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ON THE SPECTRA OF KRYPTON.

By C. RUNGE.

SPECTROSCOPICALLY krypton bears a close analogy to argon. Like argon it emits two different line spectra, one with Leyden jar and spark gap in the secondary circuit of an induction coil, the other without Leyden jar and spark gap. As in the case of argon this latter spectrum consists on the whole of less refrangible lines, and I believe, if it were possible to fill a vacuum tube with pure krypton, the color of the tube would change from yellow to blue, when the Leyden jar and the spark gap are interposed. But as far as I know there are no means as yet of getting rid of the admixture of argon. I prepared the gas after the prescriptions of W. Ramsay and Morris Travers.[1] Professor E. Warburg kindly let me have about ¾ liter of liquid air condensed in the Linde machine of the Physical Institute of Berlin. It is well known that liquid air may be kept for a considerable time in an open silvered vacuum vessel,[2] by which the influx of heat and consequently the evaporation of the liquid are greatly reduced. In an open vessel of this kind I brought the liquid

[1] W. RAMSAY and MORRIS TRAVERS, *Proc. Roy. Soc.*, **63**, 405, 1898.

[2] J. DEWAR, *Proc. Chemical Society*, Jan. 14, 1896.

air in my hand from Berlin to Hannover. It lasted four days before all was evaporated. The last fifteen liters were caught in inverted flasks over water. They contained about eighty-five per cent. of oxygen. A few liters of this supply were set apart and from the rest the oxygen was removed partly by metallic copper and partly by pyrogallic acid. I have to thank Professor Eschweiler for helping me in some of these operations. After removing the oxygen, the nitrogen had to be got rid of. Before proceeding to do this I wanted to see what the spark spectrum looked like. I took the very last that had evaporated, removed the oxygen and through the remaining sixty cubic centimeters of gas I passed a spark. The gas exploded violently. I repeated the experiment with the next but last that had evaporated and the gas again exploded, shattering the flask as in the first case. I repeated it a third time with a stronger flask. This time the flask withstood the explosion, but the large beaker glass containing a weak solution of potash into which the neck of the inverted flask dipped, was broken by the pressure propagated through the solution, although there was a considerable amount of free surface all around the neck of the flask. I then tried to explode the gas again over mercury at a reduced pressure, in order to measure the amount of contraction after explosion. But I did not succeed in making the gas explode again. The explosive ingredient, therefore, must have a smaller tension then either krypton or argon, as its percentage is increased relatively to the percentage of krypton and argon by the process of evaporation. But I am at a loss to explain of what it consists. There is an observation of Theodore de Saussure (*Ann. de Chim. et Phys.*, **44**, 52 and 53), who found that 2000 parts of air, from which all carbonic acid has been removed, when exploded with pure hydrogen contain one part of carbonic acid. There is another observation by Boussingault (*Ann. de Chim. et Phys.*, **57**, 148) that the air contains hydrogen, and lately Armand Gautier (*C. R.*, **127**, 693, 1898) has confirmed these observations as regards the air near human habitations, while he found that pure sea air contains free hydrogen to the extent of about 15 cubic

cm in 100 liters. So far as I can see, however, these facts alone do not explain the explosion.

The remaining gas was now mixed with the supply rich in oxygen that had been set apart and sparked for several days over a weak solution of potash. The last sparking was done with a surplus of oxygen until no further appreciable contraction took place and no traces of nitrogen lines were to be seen in the spectrum of the spark. After removing the oxygen by means of pyrogallic acid about 30 cubic centimeters of the gas remained. At atmospheric pressure the condensed spark between platinum electrodes showed besides some platinum lines a great number of argon lines. In the less refrangible part the principal lines of the red spectrum of argon were to be seen besides the principal lines of the blue spectrum of argon and traces of the green and yellow krypton lines. In the more refrangible part photographs of the spectrum show the "white" spectrum of argon[1] and the stronger lines of the second of the two krypton spectra described below. The argon lines are mostly widened and rather diffuse. In the vacuum tube without Leyden jar and with not too low pressure the krypton lines come out bright. At the same time the carbon bands are very conspicuous. I believe their origin is the same gas that Ramsay and Morris Travers have called metargon. A. Schuster has already called attention to the fact, that the spectrum of metargon as described by Ramsay and Morris Travers seems to be identical with the spectrum of carbon.[2] It is indeed remarkable, as Ramsay and Morris Travers have pointed out, that if metargon is a compound of carbon, it should not be absorbed by sparking it with oxygen over a solution of potash. I have convinced myself, however, that the bands in my vacuum tube coincided accurately with the carbon bands, although the gas was also sparked with oxygen over a solution of potash. In the following list I give in the first column the wave-lengths of a number of edges determined from the neighboring argon lines

[1] See J. M. EDER and E. VALENTA, *Denkschriften der Wiener Akad.*, 1896.

[2] A. SCHUSTER, *Nature*, **58**, 199, 255, 269.

and in the second column the determinations of H. Kayser and myself of the edges of the carbon bands in the spectrum of the electric arc.

Vacuum tube edges of bands	Kayser and Runge edges of carbon bands electric arc
4684.92	4684.99
4697.63	4697.62
4715.37	4715.36
4737.20	4737.23
5129.29	5129.44
5165.27	5165.38
5540.38	5540.92
5585.32	5585.56
5635.37	5635.49

The differences may well be due to errors of observation, as it is more difficult to determine the wave-length of an edge than the center of a symmetrical line. I think there can be no doubt that these bands are the same as those in the electric arc. As regards the intensities of the lines composing the bands I have, however, observed a considerable difference between the bands in the vacuum tube and in the electric arc. In the green band 5165 of the electric arc there are a series of weak triplets between strong close doublets (see the photograph given in Kayser and Runge's article, *Abhandlungen der Berliner Akademie*, 1889). In the vacuum tube the triplets are much stronger and the doublets much weaker than in the electric arc. The dispersion of the short focus concave grating with which I have been working is not great enough to study these differences satisfactorily and I have therefore not followed out the subject at present. I do not think it possible that the carbon bands are due to impurities introduced after sparking the gas. For impurities caused in the mercury pump never, as far as I know, produce the carbon bands, but invariably produce the so-called bands of carbon monoxide, which were not to be seen in my vacuum tube. I think it most likely that there is a combination of argon and carbon that is able to resist the sparking with oxygen. I noticed that the carbon bands are to be seen on photographs

that F. Paschen and myself have taken of the red spectrum of argon. Here also the gas was sparked with oxygen over a solution of potash, nevertheless the carbon was not removed. The cyanogen bands also made their appearance in the krypton vacuum tube and all the lines of the red spectrum of argon. Besides I noticed some other bands of which I do not know the origin. They have nothing to do with krypton as they were also observed in argon tubes. At first some of the nitrogen bands were to be seen; but they disappeared after I had run the tube for some time. With low pressure the carbon bands are greatly reduced in intensity; the krypton lines are also weakened and the lines of the blue spectrum of argon make their appearance. With a Leyden jar and a spark gap the spectrum of krypton changes as well as the spectrum of argon. The new lines are mostly in the blue part of the spectrum.

SPECTRUM OF KRYPTON EMITTED BY A VACUUM TUBE WITHOUT LEYDEN JAR AND SPARK GAP.

Wave-length	Intensity[1]	Number of determinations	Mean error	Lines mentioned by Ramsay and Morris Travers	Remarks
4274.09	4	7	0.02	......	
4318.70	2	5	0.03	4317	
4319.760	4	7	0.013		
4362.76	2	5	0.02	......	
4376.24	3	5	0.02	4387	
4400.05	1	2	0.03	......	
4454.07	4	8	0.03	......	
4463.82	5	8	0.03	4461	
4502.43	4	8	0.03	......	
4624.46	1	4	0.04	......	
4671.42	2	3	0.03	4671	
....	..	..	....	4736	There are some krypton lines in this neighborhood when a Leyden jar and spark gap are used
....	..	..	....	4807	
....	..	..	....	4830	
....	..	..	....	4834	
5562.363	4	7	0.020	5560.6	
5570.417	8	8	0.015	5568.8	
....	..	..	....	5829	Not seen
5871.071	8	6	0.018	5867.7	
....	..	..	....	6011	Not seen
7587.48	3	3	0.06	......	
7601.47	4	3	0.11	......	

[1] The scale of intensity is weakest :1; strongest :10.

SPECTRUM OF KRYPTON EMITTED BY A VACUUM TUBE WITH LEYDEN JAR AND SPARK GAP.

Wave-length	Intensity	Number of determinations	Mean error	Remarks
3654.11	3	3	0.03	
3686.26	1	3	0.035	Diffuse
3741.85	3	3	0.02	
3778.29	4	2	0.04	
3783.40	4	2	0.03	
3912.36	1	2	0.10	Diffuse
3920.59	1	2	0.10	Diffuse
4057.16	2	2	0.035	
4065.19	3	3	0.05	Diffuse. Argon?
4088.53	6	3	0.07	
4145.27	3	3	0.035	Possibly sulphur 4145.266
4293.10	5	3	0.02	(Eder and Valenta)
4318.22	2	3	0.07	
4355.62	5	4	0.04	
4436.96	2	4	0.05	
4464.11	1	3	0.04	Diffuse
4577.31	4	4	0.02	
4615.48	4	4	0.02	
4619.30	5	4	0.03	
4634.07	4	4	0.02	
4680.67	3	4	0.05	
4694.82	2	3	0.05	
4702.73	1	2	0.02	
4739.13	5	4	0.035	
4762.66	2	2	0.06	
4825.38	1	2	0.15	
4832.22	2	2	0.03	
4844.58	1	2	0.035	
5208.57	1	2	0.04	
5292.37	2	2	0.05	
5419.38	2	2	0.025	

To select the lines due to krypton I compared the photographs with photographs taken some years ago by Paschen and myself of the spectrum of argon. On each of the two plates to be compared I removed the gelatine on one side of a straight line, cutting the lines of the spectrum at right angles. The plates were then laid together in such a manner that the parts where the emulsion was left were in contact along the cut but on different sides. In this way the plates can be examined under the microscope and the lines that exist only on one of the plates are detected. None of the lines were measured visually. The

photographs cover the region from $\lambda = 2400$ A. U. to $\lambda = 8000$ A. U. The wave-lengths were interpolated, using the argon lines, some mercury lines and the D lines as standards. For the wave-lengths of the argon lines H. Kayser's[1] measurements have been used and some unpublished measurements that F. Paschen and myself have made by comparison with iron lines. In the least refrangible part I used my own measurements[2] of the argon lines, which are also based on Kayser's argon lines of the second order. The photographs were taken with a Rowland concave grating of one meter radius. The mounting has been described in the paper on the series spectra of oxygen, sulphur and selenium.[3]

These lists are, I presume, very far from complete. As long as krypton is so strongly diluted with argon the weaker krypton lines are likely to escape notice, or may even not appear at all.

The analogy of the first spectrum of krypton to the red spectrum of argon is further borne out by the fact that the wave-numbers of several pairs of lines show equal differences. For simplicity's sake I have in the following table not corrected to *vacuo*, as the correction does not affect the difference of wave-numbers to any appreciable extent.

λ	$1/\lambda$	Difference
4274.09	23396.79	945.42
4454.07	22451.37	
4318.70	23155.12	944.89
4502.43	22210.23	
5562.363	17977.97	945.30
5871.071	17032.67	
	Mean	945.20

The deviations from the mean are : 0.22, 0.31, 0.10, which correspond to the differences in wave-length : 0.04, 0.06, 0.03. These differences are well within the limits of error.

[1] H. KAYSER, this JOURNAL, 4, 1896.

[2] C. RUNGE, this JOURNAL, 9, 281, 1899.

[3] C. RUNGE and F. PASCHEN, this JOURNAL, 8, 70, 1898.

RADIATION FROM A PERFECT RADIATOR.

By W. E. Wilson.

Although Kirchhoff introduced the conception of a perfectly "black" body in the deductions of his well-known law connecting the emissive and absorptive power of a body in regard to radiant heat, he seems not to have investigated the subject experimentally, but points out that the law of radiation for a truly "black body" must necessarily be of a simple character.[1]

During a conversation with Mr. Lanchester in the autumn of 1895, he pointed out to me that he thought if we took a hot enclosure into which there was only a small aperture and measured the radiation passing out through this aperture that the internal walls of the enclosure would behave as a perfect radiator, whether they were a bright metallic surface or coated with lampblack or any other substance.

About the same time Ch. E. St. John also pointed out that in a heated enclosure, such as a fire-clay furnace, metals raised to a red heat appeared of almost equal brightness whether their surfaces were polished or blackened with oxide.

As all investigations up to this time on the laws of radiation were made with the assumption that lampblack was a perfectly black body and therefore a perfect radiator, it seemed of interest to compare the radiation from it with that coming from a hot enclosure with a small aperture, and which would evidently behave as a perfect radiator.

We procured a half gallon tin *T*, and soldered it by the neck into a large biscuit box *B*. Some water was placed in the biscuit box and kept boiling with a Bunsen burner so that the tin enclosure was completely surrounded with steam at 100° C.

A Boys' radio-micrometer *R* was mounted in front of the aperture and suitable screens *S* were interposed so as to cut off all radiation except that coming from the enclosure through the

[1] G. Kirchhoff, *Pogg. Ann.*, 109, 292, 1860.

aperture. The outside of the biscuit box near the aperture was coated with lampblack, and by slightly moving the box we could allow this blackened surface to radiate to the radio-micrometer instead of the enclosure.

The temperature of this blackened surface of the biscuit box must have been very nearly the same as that of the enclosure, but

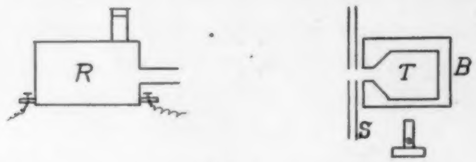


FIG. 1.

we were astonished to find that if we represented the radiation from the enclosure as 100, the radiation from an equal area of the blackened surface was only about 60.

The result of this rough experiment was so interesting that I determined to investigate the law connecting the *total* radiation and temperature of such a theoretically perfect radiator.

An enclosure was formed of a large plumbago crucible with a cover of the same material. This stood in a Fletcher's gas furnace and could be raised to any desired temperature.

A hole was bored through the walls of the furnace and also through one side of the crucible. This hole was lined with a porcelain tube through which could be seen the interior of the crucible.

A second porcelain tube also passed into the crucible and was used to carry a thermo-electric junction, made of pure platinum and platinum-rhodium. The current from this was measured by a D'Arsonval galvanometer of low resistance, and its calibrating curve, which was practically a straight line, was obtained by inserting the junction in steam at 100° C., in pure lead freezing, and in pure gold freezing. The radio-micrometer was used to measure the radiation coming from the enclosure, but as this instrument was so sensitive as to give a considerable deflection before the crucible was even red hot, some means had to be devised to

reduce the sensibility of the instrument by a known amount as the temperature of the crucible was raised.

Instead of allowing the radiation to fall directly on the radio-micrometer it was received by a concave silver-on-glass mirror, and this formed an image of the aperture of the hot enclosure on the thermo-couple of the radio-micrometer. In

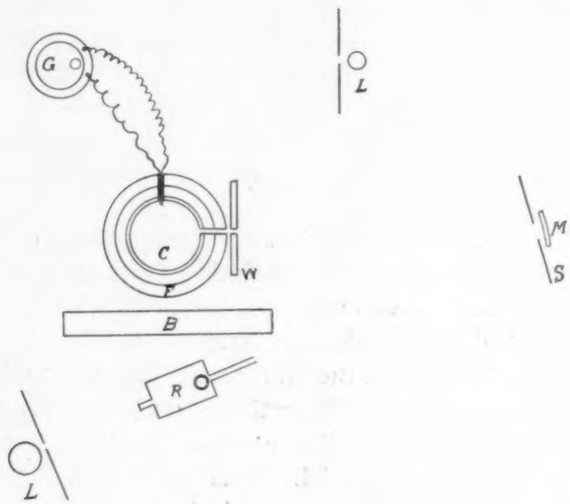


FIG. 2.

front of this mirror were placed a set of stops of known area, and by changing them the intensity of the image of the aperture and thus the deflections of the radio-micrometer could be altered.

A hole was bored right through the radio-micrometer and provided with a low power positive eyepiece; by looking through this I could see an image of the aperture and also the thermo-couple hanging in front of it. By this means I could be sure that the image of the hot aperture always completely covered the thermo-couple of the radio-micrometer.

In front of the hot aperture was placed a copper screen through which a current of cold water was kept flowing. This screen was provided with a hole about 2 mm in diameter through which the radiation passed from the enclosure to the mirror and

then to the radio-micrometer. The hole was of such a size that the inside of the porcelain tube could not be seen from the radio-micrometer, but only a small area of the inside of the hot enclosure.

Observations were made by raising the temperature of the enclosure to about 1200° C.; the gas was then cut off, and the furnace and crucible were allowed to cool very slowly. Readings were then taken at frequent intervals of the deflections of the radio-micrometer, and simultaneously the temperature of the enclosure.

TABLE I.

T° absolute	Radiation	T° absolute	Radiation
1,317	1,300	787	155
1,266	1,080	761	133
1,206	920	751	127
1,193	824	726	112
1,161	736	708	99
1,105	560	700	94
1,075	460	676	81
1,050	456	663	74
1,022	400	645	65
1,007	436	630	60
988	360	614	52
963	350	593	46
945	310	582	43
921	284	551	33
901	262	541	32
875	230	522	24
855	208	491	19
826	194	466	16
805	172		

In Table I the values of a set of readings thus obtained are given, and in Fig. 3 the logarithms of these values are plotted. The straight line drawn on the chart represents a fourth power curve, and it will be seen that the observations lie very close to it, and thus seem to confirm Stefan's[1] law of radiation where $R = a\,T^4$.

In another set of readings the observations did not lie quite so close to this curve, but seemed to conform better with $R = a\,T^{4.3}$.

[1] I. STEFAN, *Wien. Ber.* (2),, **79**, 391–428, 1879.

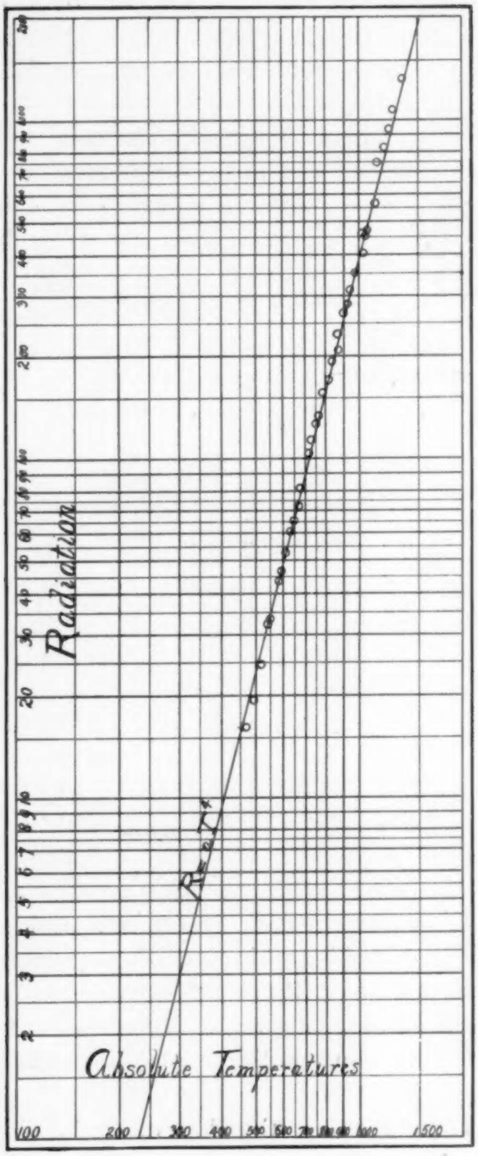


FIG. 3.

While this investigation was being carried on, Lummer and Pringsheim[1] were also working at the same subject, and their very carefully carried out experiments seem to confirm mine, and give also nearly a fourth power law.

It is only by knowing the true law of radiation that we can possibly measure directly the temperature of the Sun, and therefore any advancement in our knowledge on this subject is of the greatest importance.

In our investigation here in 1893 on the Effective Temperature of the Sun[2] we had first to study the law of radiation from a platinum strip which was raised to any desired temperature by an electric current, and the radiation from which then balanced the radiation coming from the Sun; the balancing instrument being a duplex Boys' radio-micrometer especially designed for this work.

In order to cut off all radiation from the incandescent platinum strip except that coming from a known area, the strip was covered with a water-jacket with a small hole through which the radiation passed into the radio-micrometer. The interior walls of this jacket were highly polished and plated with gold.

Since this investigation was made it has been pointed out that if we have a hot body inside an enclosure the inside walls of which are perfect reflectors, and allow heat to pass out through an aperture in the walls, the hot body will behave as if it was a perfect radiator. Now we assumed that the radiation from our platinum strip was only $\frac{35}{100}$ of that from a perfect radiator,[3] whereas our strip as mentioned was probably behaving very nearly as a perfect radiator. The fact that the law of radiation which we then found from this strip was a fourth power one, and the same as I have since found from a perfect radiator, seems also to indicate that the strip was behaving as a perfectly black body.

[1] O. Lummer und E. Pringsheim, "Die Strahlung eines 'schwarzen' Körpers zwischen 100° und 1300° C." *Wied. Ann.*, **54**, 1897.

[2] Wilson and Gray, "Effective Temperature of the Sun." *Phil. Trans. Royal Society*, **185**, 1894.

[3] Schleiermacher, *Wied. Ann.*, **26**, 287, 1885; Rosetti, *Phil. Mag.*, **8**, 445, 1879.

If this surmise is correct we must clearly multiply the value we obtained of the solar temperature by $\sqrt[4]{\frac{100}{35}} = 1.30$. Therefore the effective solar temperature would be 8700° C. $\times$ $1.30 = 11300^\circ$ C. An experimental investigation is now being made to clear up this point.

June 1, 1899.

ON THE SPECTRA OF STARS OF SECCHI'S FOURTH TYPE. I.

By GEORGE E. HALE and FERDINAND ELLERMAN.

THE rapid progress of stellar spectroscopy during recent years, which has been due almost entirely to the development of photographic methods, has naturally followed three principal lines:

1. The determination of the general characteristics of stellar spectra, permitting a classification of stars on the basis of spectral types.

2. The measurement of the wave-lengths of dark and bright lines, for the purpose of identifying the substances present in stellar atmospheres.

3. The measurement of the displacement of stellar lines with reference to the lines of an artificial comparison spectrum, giving a means of determining the velocity of stars in the line of sight.

The measurement of the radial motion of stars, first attempted by Huggins with the inadequate instruments of a third of a century ago, has already reached an advanced stage of development. This is largely due to the work of Vogel, who first employed photographic methods in this field. The photographs taken at Potsdam for the purpose of Vogel's investigations have served, in the hands of Scheiner, for the accurate determination of the wave-lengths of numerous stellar lines. With the exception of this research, however, but little systematic work has been done in this direction.[1] An extensive field of investigation, hitherto almost unexplored, here lies open to students of astrophysics. Fortunately many of the brighter stars are within the reach of moderate apertures, and may be investigated with but small

[1] Professor Keeler is engaged in an important investigation of the spectra of stars of Secchi's third type.

additions to the instrumental equipment of the average observatory.

The study of the general characteristics of stellar spectra has been greatly facilitated by the use of the objective prism, which has been applied with such striking success by Pickering at the Cambridge and Arequipa stations of the Harvard College Observatory. The recent work of Vogel and Wilsing with the small spectrograph of the Potsdam Observatory, and the photographs of stellar spectra made in England and at the Cape by Huggins and Lockyer and McClean afford additional material for an extensive study of stellar development.

An examination of these results will show, however, that our knowledge of the spectra of stars of Secchi's fourth type (Vogel's III*b*) has advanced but little since the publication in 1884 of Dunér's memoir "Sur les Étoiles à Spectres de la Troisème Classe." Two causes sufficiently explain this fact. In the first place none of the stars of the fourth type are brighter than the 5.5 magnitude; and further, the spectra are so faint in the more refrangible region that but little is recorded on ordinary plates used with an objective prism. Thus the great store of negatives belonging to the Harvard College Observatory, so rich in other respects, contains few data available for the study of the spectra of these stars.

In planning the work of the Yerkes Observatory it was felt that the 40-inch refractor should preferably be employed in fields of investigation where its great light-gathering power would be likely to prove of most service. The objective of this instrument, which is corrected for visual observations, is especially adapted for the examination of the less refrangible regions of stellar spectra. The present investigation, which relates particularly to the visible spectra of faint red stars, was accordingly undertaken in November 1897.

RESULTS OBTAINED BY PREVIOUS OBSERVERS.

In his early survey of stellar spectra Secchi divided the stars into three classes, of which the third was given up to red stars.

Most of the stars of this character examined were naturally of the true third type; but one, *Lalande* 12561, is of the fourth, though it was classed by Secchi in the first part of his memoir, *Sugli spettri prismatici delle stelle fisse* (1867) with *α* Herculis, in the following words (*Catalogo*, p. 14.)

In conclusion, this is of the type of *α* Herculis, but with the dark zones lacking, while its own zones are so broad that some of them embrace two of those of *α* Herculis.

In the second part of the memoir it appears that the distinctive characteristics of fourth type spectra were recognized in the course of a survey of some twenty red stars from Schjellerup's catalogue. In describing the spectrum of 152 *Schjellerup* as characteristic of the class Secchi remarks (p. 9):

This type is composed of but three principal zones; a bright one in the green, a fainter one in the blue, and a pretty bright one in the red. This latter zone is frequently subdivided into other lesser zones.

This type differs essentially from the third, not only by the division of the zones, which have twice the breadth, but also because the zones have the greater luminous intensity on the opposite side; *i. e.*, in the fourth type the light increases in intensity from the red toward the violet, while in the third type the reverse is true. Thus if the third type were represented by a system of columns, the fourth type would be represented by cavities, supposing the illuminating light to be directed from the same side.

These stars also contain bright lines like those of the metals, and it is singular that these occur at the brightest extremity of the colored zones.

Few objects of this class were known to Secchi, but many were discovered in the subsequent observations of Vogel, D'Arrest, Pickering, and Dunér. The memoir published by Dunér in 1884, "Sur les Étoiles à Spectres de la Troisème Classe,"[1] together with Vogel's observations made with the 27-inch refractor of the Vienna Observatory,[2] afford the best data for a study of the spectra. A complete list of all fourth type stars hitherto discovered has recently been compiled by Espin,[3] who has himself made many additions to the number.

[1] *Svenska Vetenskaps-Akademiens Handlingar*, Vol. XXI, No. 2.

[2] *Publicationen der Astrophysikalisches Observatorium zu Potsdam*, Vol. IV, Part 1.

[3] *M. N.*, **58**, 443, June 1898.

Dunér's important observations, which will frequently be referred to in the present series of papers, were made with several direct vision spectroscopes of different dispersive powers attached to the 10-inch refractor of the Lund Observatory. In spite of the small aperture of his telescope, the low dispersion which was necessarily employed, and the serious difficulties that are almost invariably encountered in visual observations of faint spectra, Dunér's results are of the highest value, and have been confirmed in almost every particular by our photographs. For purposes of comparison Dunér's drawings of fourth type spectra are reproduced from his memoir (Plate II).

While it is undoubtedly true, as Dunér has pointed out in his memoir, that many of Secchi's results are unreliable, it should nevertheless be remembered that the earlier observer was a pioneer in this field, and that his instruments were hardly adequate for such difficult observations. He deserves credit for having discovered this type of spectrum, and for giving evidence of the presence of carbon in the atmospheres of fourth type stars. His most conclusive measures, as quoted by Dunér (p. 122) are as follows:

Distances between the sodium line and the bands

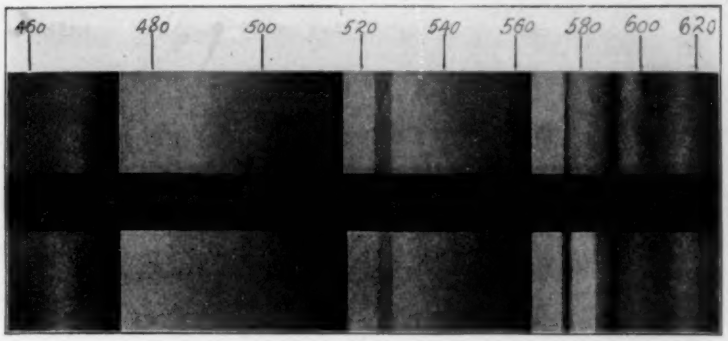
(A) in the spectrum of 152 *Schj.*	(B) in the spectrum of benzine gas
4.76	4.83
1.29	1.22

As Dunér remarks, Secchi's many inaccuracies cast doubt upon these as well as other results, but they are interesting as the earliest recorded evidence of the carbon origin of the bands.

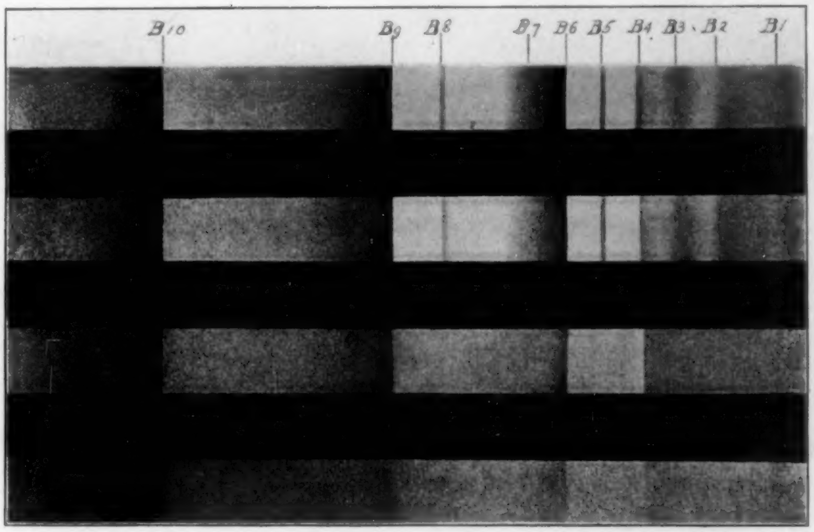
In his observations at Bothkamp and in his later work with the 27-inch Vienna refractor Vogel measured the spectra of stars Nos. 51, 78, 152 and 273 in Schjellerup's catalogue, and that of *DM.* 34° 4500.[1] His results are given in the following table, which is taken from Vol. IV of the Potsdam Publications:

[1] VOGEL's drawings of the spectra of 152 *Schjellerup* and *DM.* 34° 4500 are reproduced in Plate II from the memoir cited above.

PLATE II.



SPECTRA OF FOURTH TYPE STARS (VOGEL).
1. 249*a* Schjellerup.
2. 152 Schjellerup.



SPECTRA OF FOURTH TYPE STARS (DUNÉR).
1. 152 Schjellerup.
2. 273 Schjellerup = 19 Piscium.
3. 7 Schjellerup.
4. 541 Birmingham.

WAVE-LENGTHS DETERMINED BY VOGEL.

Object	Schj. 152 (Vienna)	Schj. 152 (Vienna)	Schj. 152 (Bothkamp)	DM. +34° 4500 (Vienna)	Schj. 273 (Bothkamp)	Schj. 78 (Bothkamp)	Schj. 51 (Bothkamp)	Mean
Beginning of spectrum.			660					660
Dark band					656			656
Dark band			622		622	623		622
Dark band					6065			6065
Line in a band........	5891		5893	5889	589	590		5893
End of band..........	5848							5848
Line..................	5741		5758	5750	578	5755		5757
Line beginning a band.	5621	5625	5628	5620	564	564	5640	5631
Line..................			552		552			552
Line..................			544					544
Group of lines			528	527	529			528
Line beginning a band.	5159	5163	5156	5161	516	515	5165	5159
Line..................	5132							5132
Beginning of band	4716		4735	4744	472	473		4729
Band			437					437
End of spectrum			430					430

Dunér's measures of fourth type (III*b*) spectra, as tabulated on p. 122 of his memoir, are given below.

WAVE-LENGTHS DETERMINED BY DUNÉR.

Object	19 Piscium	132 Schj.	152 Schj.	132 Schj.	152 Schj.	Wave-length
Band 2	621					621
Band 3	6048					6048
Band 4 (max.)	5895	5884		5895	5910	5898
Band 5	5760	5757	5747	5762	5761	5760
Band 6 (beg.)		5640	5624	5633	5634	5633
Band 7	551					551
Band 6 (end)......					545	545
Band 8	5285				5280	5283
Band 9 (beg.)......		5167	5159	5160	5164	5163
Band 9 (end)......					496	496
Band 10 (beg.)		4714	4720	4729	4739	4727
Band 10 (end).....	463					463
End of spectrum...			437			437

The combined results of the two observers, compared with Kayser and Runge's wave-lengths of the hydrocarbon bands, are contained in the following table:[1]

[1] SCHEINER'S *Astronomical Spectroscopy*, Frost's translation, p. 314.

COMPARISON OF WAVE-LENGTHS.

Object	Vogel	Dunér	Mean	C_mH_n
Spectrum begins	660		660	
Dark band	656		656	
Dark band	622	621	6215	
Dark band	6066	6049	6058	6060. Middle of red band
Line in a band	5894	5899	5897	
End of a band	5849		5849	
Line....................	5758	5761	5760	
Line beginning a band ...	5632	5634	5633	5635.43. Beginning of yellow band
Line....................	552	551	5515	
Line....................	544	545	5445	
System of lines	528	5284	5282	
Line beginning a band....	5160	5164	5162	5165.30. Beginning of green band
		496	496	
Line....................	5133		5133	
Beginning of a band......	4730	4728	4729	4737.18. Beginning of blue band
		463	463	
Band....................	437	437	437	4381.93. Beginning of fifth band
End of spectrum	430		430	

As the hydrocarbons are all reduced to acetylene (C_2H_2) at high temperatures, and are characterized by a common spectrum which perhaps belongs to this substance, Scheiner remarks:

We may, therefore, go a step farther and consider that in the stars of class III*b* carbon and hydrogen are united in the form of acetylene, which is the first combination of these two elements which would ensue as the temperature fell.

Of the dark lines measured by Vogel and Dunér 5897 is considered by Scheiner to coincide with D and 5282 with the E group in the solar spectrum. The other lines could not be identified. He points out, however, that strong lines have been recorded at the following wave-lengths in the spectrum of *a* Orionis:

Vogel	Huggins	Dunér
5143	5143	5146
5451	5449	5449
5529	5526	
5760	5750	

Scheiner states that under the circumstances the agreement may be considered satisfactory, and therefore does not think it "hazardous to assert that metallic lines of type III*b* (IV) resemble those of type III*a* (III) so that the differences in these two subtypes are only due to the different chemical combinations present in their atmosphere."

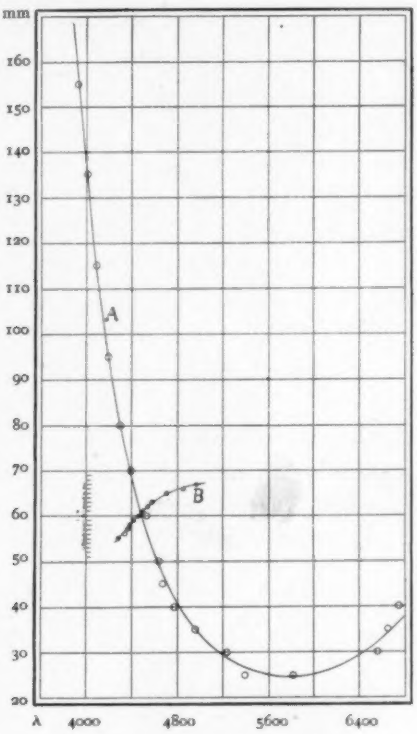
A discussion of Dunér's views regarding the development of fourth type stars, which are entitled to the greatest weight, will be deferred until after the numerical results obtained in our investigation have been given.

Fifty-five stars of the fourth type are catalogued in Dunér's memoir. Thanks to the photographic work of the Harvard College Observatory and the visual observations of Espin, this number has been increased to 242. Out of this number there are but three stars in the northern hemisphere and four in the southern that are brighter than the sixth magnitude. Of the stars which have been observed photometrically Espin finds that between the magnitude 6.1 and 7 there is a total of 23 stars; between 7.1 and 8, 39; between 8.1 and 9, 76; below 9, 80. In addition to the faintness of these objects the fact that the most characteristic portions of their spectra are in the red, yellow, and green tends to increase the difficulty of studying them photographically. It is evident that instruments especially adapted for the investigation of faint objects must be employed for the purpose.

DESCRIPTION OF THE INSTRUMENTS.

The principal instruments used in this investigation were the 40-inch refractor of the Yerkes Observatory and a stellar spectrograph containing one or three prisms. The object-glass of the telescope, which was made by Alvan Clark & Sons, has a clear aperture of 40 inches (102 cm). Its focal length for distinct vision, as determined from photographs of star trails, is 1936±cm. The focal length has been measured at various temperatures, and has been found to decrease 17.5 mm for a fall in temperature of 45°C. The form of the color curve correspond-

ing to various temperatures has been determined by Professor Frost, Professor Wadsworth, and one of the present writers. A full discussion of these results will soon be published by Professor Frost; but for the purposes of this paper, the color curve corresponding to a temperature of —18°C., and illustrated in the



COLOR CURVE OF FORTY-INCH OBJECTIVE.

accompanying figure, will suffice. It will be seen that the curve is flat enough to permit fairly satisfactory photographs of the spectral region lying between λ 5000 and λ 6500 to be taken in a single exposure. In the work on the yellow and green regions of the spectrum the slit of the spectrograph has ordinarily been set in the focus of the 40-inch objective, which corresponds to λ 5000. The spectra of fourth type stars generally increase in

brightness from the head of the yellow carbon band toward a maximum in the green. On account of the loss due to the form of the color curve and the fall in the curve of sensitiveness of ordinary isochromatic plates in the neighborhood of the *b* group, the intensity of the photographed spectra is more nearly uniform in the green than it should be. It must be borne in mind, therefore, in examining the photographs of fourth type spectra reproduced in these papers, that the green region should ordinarily have a considerably greater relative brightness than the plates give it. The same may be said of the less refrangible half of the bright zone in the yellow.

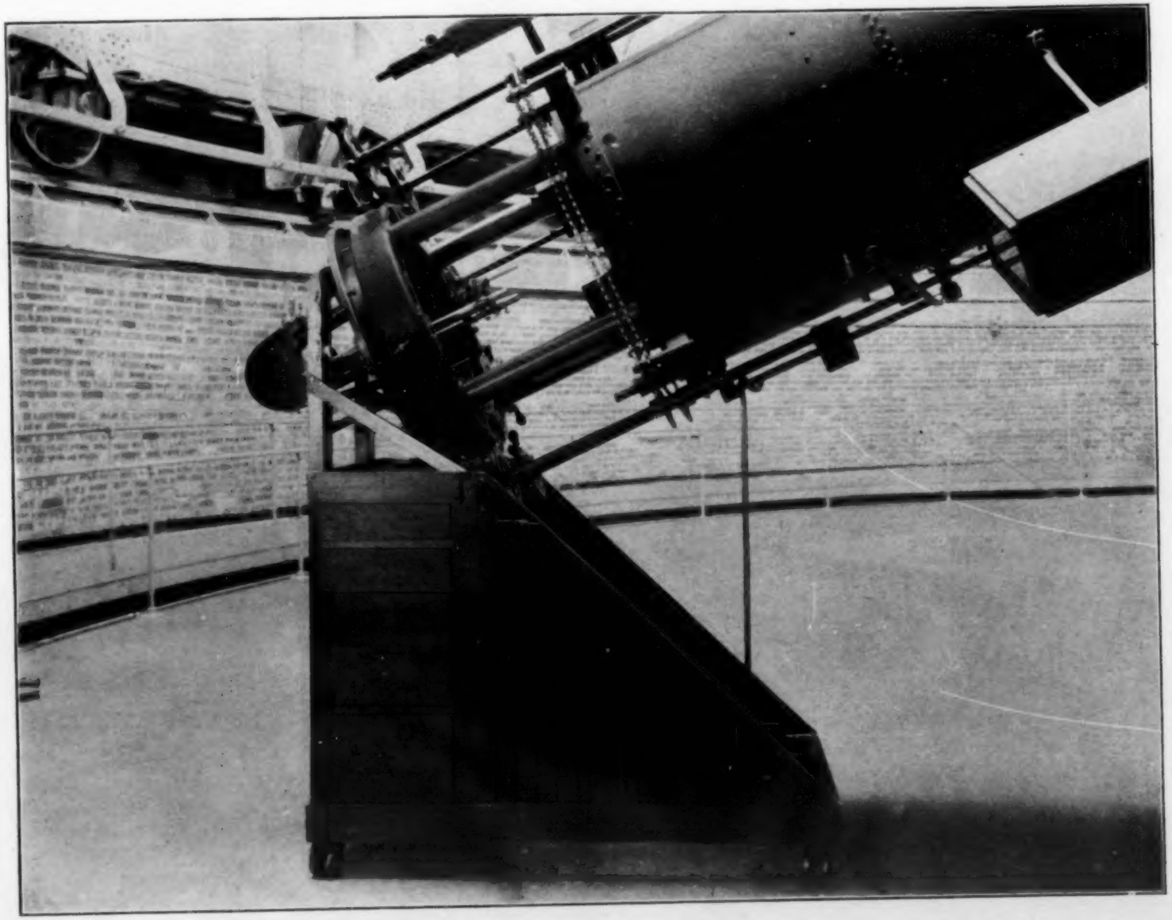
Photographs of the more refrangible portions of the spectra of some of the brighter fourth type stars were taken before a correcting lens had been obtained, but on account of the steepness of the color curve in the blue, only a limited region could be satisfactorily photographed in a single exposure. The correcting lens, which has been made by Brashear after curves calculated by Professor Wadsworth from Keeler's formulae,[1] is so effective that it permits the entire blue portion of fourth type spectra to be photographed on a single plate. It consists of a compound lens of 32 mm aperture, supported in the cone of rays from the 40-inch objective at a distance of 30 cm from the slit. When the lens is in place (it is carried by an adapter accurately centered in the tailpiece of the telescope) the divergence of the cone of rays after passing through it is 1 : 15.8, while the ratio of aperture to focal length of the collimator objective is 1 : 16.3. The introduction of the correcting lens causes the focal plane corresponding to λ 4500 to move about 60 mm toward the 40-inch objective. At the same time the color curve is made much flatter in the blue region, as is indicated by the curve (*B*). The lens not only increases the extent of the spectrum that can be photographed on a single plate, but also materially reduces the exposure time by rendering the task of guiding less difficult. The small star image seen when the correcting lens is in place can be kept on the slit much more easily than the expanded disk obtained without the lens.

[1] See this JOURNAL, 1, 101, February 1895.

The spectrograph, a photograph of which is reproduced in Plate III, was built by Brashear for the 40-inch telescope. As originally constructed, this instrument was in almost every respect similar to the spectrograph designed by Keeler for the Allegheny Observatory. As the result of a series of experiments made with the spectrograph attached to the 12-inch refractor of the Kenwood Observatory, and further work with the instrument in conjunction with the 40-inch refractor of this Observatory, the spectrograph has been reconstructed in our instrument shop after designs by Professor Wadsworth. The supporting drum supplied by Warner & Swasey to carry the spectrograph, which was made interchangeable with the tailpiece of the telescope, is no longer used. Instead, the instrument is now clamped to a large ring which was designed to carry the solar spectroscope and spectroheliograph. This ring is supported by four heavy tubes, which can be racked into the body of the telescope by means of a hand crank connected with a worm gear. In this way the spectrograph can be moved along the optical axis of the telescope for focusing the star on the slit, and the large ring can be racked up out of the way when the telescope is wanted for micrometric work. The heavy brass casting which supports the collimator of the spectrograph is held (by means of centering screws) in the center of a ribbed iron casting 85 cm in diameter, which is fitted by a cone bearing to the ring carried by the telescope. This casting has a gear cut on its circumference, which permits the spectrograph to be rotated by either one of two pinions attached to the ring. When set at the desired position angle it is clamped in place by suitable bolts.

The collimator objective has an aperture of 31 mm and a focal length of 507 mm. The collimator tube is supported within an outer fixed tube, and has a range of motion of 130 mm along the axis of the telescope. In general this adjustment is not used, the collimator being kept at a certain scale reading, and the slit brought into the focal plane by moving the entire spectrograph in the manner indicated above.

PLATE III.



THREE-PRISM SPECTROGRAPH ON CARRIAGE.

The prism train ordinarily employed contains three 60° flint prisms of index $n = 1.6960$. With this train the deviation for $H\gamma$ is about 180°. The prisms are mounted on leveling screws, and are held in place on their supports by adjustable springs pressing against their upper surfaces. They are connected by a minimum deviation device designed and made by Brashear. After being set for a certain region, they are always clamped firmly in place by means of screws which pass through the top of the prism box and press against the top of the prism supports. The prisms have a distinctly yellowish color, and undoubtedly exercise considerable absorption in the blue and violet. The exact amount of this absorption has not yet been determined. The temperature of the air in the prism box is measured by a thermometer, the bulb of which is nearly in contact with the back surface of the second prism.

Three cameras of different focal lengths have been employed at various times. The first, which was supplied by Brashear with the spectrograph, has an aperture of 31 mm and a focal length of 508 mm. The second, which was made in our instrument shop, is used with an achromatic objective of 31 mm aperture and 253 mm focal length, also supplied by Brashear for visual use with a short observing telescope. As it does not give a sufficiently flat field for the best photographic results, this objective has been replaced by a photographic doublet of 37 mm aperture and 271 mm focal length. This performs admirably, giving a flat field over a long range of spectrum. In all cases the best results have been obtained when an objective corrected for the *visual* rays has been employed in the collimator.

Many of the earlier photographs of the fainter stars were made with the dispersion of a single heavy flint prism and the long (508 mm) camera. It was subsequently found, however, that much better results could be obtained, with shorter exposures, by using three prisms and a short camera. All negatives taken recently have been made in this way. A supplementary camera with photographic doublet of 40 mm aperture and about 15 cm focal length has been provided for use on the fainter stars.

The slit jaws are of polished speculum metal, as first used by Huggins. Arrangements had been provided for observing the star reflected from the first prism face, as is done at Potsdam, but a comparison of the two modes of guiding showed the reflecting slit method to be more delicate and more satisfactory in other respects. The light reflected back from the inclined slit-jaws meets a right-angle prism supported a short distance in front of the slit and just outside the cone of rays from the objective. After passing through the prism the rays are rendered parallel by a lens, and are brought to the observer's eye after two more reflections. The eyepiece is placed at a convenient point just above the prism box. During the exposure the observer keeps the star image on the intersection of the slit and a fine line engraved across it at right angles, by means of the electric slow motions of the 40-inch telescope. Stars as faint as the eighth magnitude can be satisfactorily followed in this way.

The width of the spectrum can be limited, if necessary, by adjustable jaws behind the slit. The width of the slit itself is read on the divided head of a micrometer screw, provided with right and left-handed threads, which move the jaws outward from the axis of collimation.

The comparison spark apparatus is so mounted that the (iron) electrodes can be swung into position immediately in front of the slit, at a distance of 23 cm from it. On the same support with the electrodes is a lens of 19 mm aperture, having the iron poles in one conjugate focus and the slit in the other. The angular aperture of the lens as seen from the slit is 1 : 7.4. As the ratio of aperture to focal length of the collimator objective is 1 : 16.3, the entire lens is always filled with light from the spark. Before making the exposure for the star a metal disk containing a suitable aperture is turned into position before the slit. The form of the aperture is such that a narrow occulting bar covers the middle of the slit, where the star's image is to fall, while light from the spark is permitted to pass on both sides of the center. The spark, which is produced by an App's induction coil with condenser in the secondary circuit, is given an

exposure of seven or eight seconds. The spark apparatus is then turned out of the way, the disk rotated to a point where the middle of the slit is exposed, the length of the slit reduced to correspond with the width of the occulting bar, and the desired exposure is given to the star. At the end of the exposure the middle of the slit is again covered with the bar and the light of the spark admitted as before. Thus if a change of temperature occurs during the exposure to the star, the spark lines photographed at the end will be shifted with respect to those first recorded. If the change of temperature is fairly uniform and the star lines are not shifted by motion in the line of sight, the center of the widened iron lines should coincide with the center of the corresponding star lines.

During the long exposures which have been necessary for the fainter stars the change of temperature in the prism box, which sometimes amounts to as much as 4° C., has in certain cases seriously affected the definition of the spectra. In work of this kind it is desirable to adopt some means of counteracting such variations, which not only decrease the sharpness of the spectra, but tend to introduce errors into the determinations of wavelength. With short exposures, however, the temperature change is not sufficient to affect the results.

As Plate III indicates, the spectrograph, when not in use, stands on a carriage mounted on rollers. The operation of attaching it to the telescope is a very simple one, and can easily be effected in about ten minutes. During the operation the telescope is securely anchored to the rising floor (which stands at its highest level) by means of a heavy steel bar.

When combined with a single prism (see Plate IV) the camera stands at such an angle that it is difficult to prevent flexure during long exposures. For this reason the 508 mm camera is no longer used in this way. As has been stated above, much better spectra, on a larger scale, can be obtained with shorter exposures with three prisms and the 271 mm camera. This short camera, and the still smaller one provided for very faint stars, are so well supported that they give no evidence of flexure when

used with a single prism. At present three prisms are almost invariably employed, and in this case no difficulty from flexure is experienced with any of the cameras.

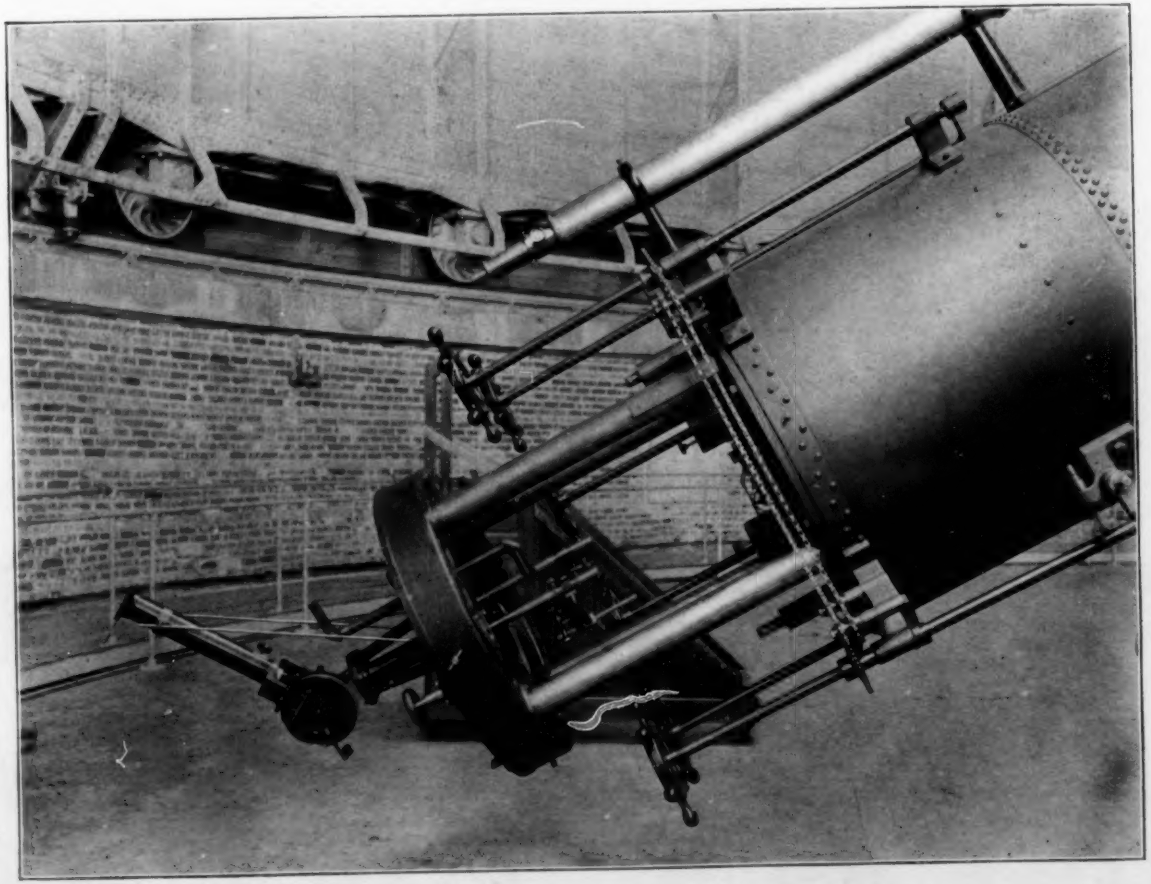
Although the diameter of the first diffraction ring in the star image given by the 40-inch objective is $0.227''$ (for $\lambda = 4600$),[1] it is impracticable to use a slit of this width in ordinary spectrographic work. If the objective were quite free from chromatic aberration, and the seeing perfect, the case would be entirely different from what it is in practice. Under ordinary conditions the minimum slit-width varies directly as the focal length of the telescope employed. For the brighter stars, when it is not desired to photograph a considerable range of spectrum, slit-widths ranging from 0.01 mm to 0.04 mm may be used to advantage with an instrument having the great focal length of the 40-inch telescope. In Professor Frost's investigations of stellar motions in the line of sight such widths are actually employed. But in our work on the faint stars of the fourth type experience has shown that the best results follow from the use of slit-widths as great as 0.1 mm. As the camera lens commonly preferred has a focal length whose ratio to the focal length of the collimator objective is 1 : 1.87, it is evident that the breadth of the spectrum and also the width of the lines are reduced in this ratio. With a slit-width of 0.15 mm, and a dispersion of three 60° prisms, the yellow and green regions of the spectrum of 280 *Schjellerup* (mag. 7.8) required an exposure of nine hours.[2]

Our study of the subject, and the experience resulting from the use of the 40-inch telescope for spectrographic investigations, have tended to confirm all that has been said by others regarding the advantages of a long collimator combined with a relatively short camera. In conjunction with Professor Frost we have designed a new spectrograph for the large telescope, in which it is purposed to use a collimator objective of from 30 to 40 inches

[1] The components of κ Pegasi have been seen and measured with the 40-inch telescope when their distance was about $0.1''$.

[2] This photograph has been reproduced in Yerkes Observatory *Bulletin* No. 7. With the same optical combination, and a slit-width of 0.075 mm, the green bands in the spectrum of α Orionis were photographed in twenty seconds.

PLATE IV.



One Prism Spectrograph attached to Forty-Inch Telescope.

focal length. There is every reason to expect that with this instrument better photographs than any we have hitherto obtained can be made with shorter exposures.

The width of the spectra photographed with the three-prism spectrograph and 271 mm camera is ordinarily about 0.18 mm. There would be no disadvantage in having the width less than this, but with the present ratio of camera to collimator it is difficult to make it much less when the exposure is continued several hours. The great length of the telescope tube causes it to sway more or less under certain conditions, though the adjustable canvas screen over the observing slit usually excludes the wind pretty effectually. The three prisms have a (visual) resolving power of about 33000 for λ 4860, but with the slit-widths employed in the present investigation only a small fraction of this is realized. In the region near λ4400 it is possible to separate on the photograph lines 0.8 tenth-meter apart, while at λ5600 lines 1.3 tenth-meters apart have been resolved. The scale of the negatives made with a dispersion of three prisms and the 271 mm camera is such that at λ4400 1 mm = 18.5 tenth-meters; at λ5350 1 mm = 49.6 tenth-meters.

It will be seen that the circumstances were not especially favorable for the accurate measurement of radial velocities, and when the work was undertaken it was not proposed to attempt such determinations for the faint stars under investigation. Nevertheless all precautions were taken to avoid systematic errors and the approximate velocities of a few of the brighter stars of the fourth type have been determined. The problem is hardly comparable with that of measuring the radial velocities of stars of other types as bright as the fourth magnitude, for which the exposure times are short, the displacements due to temperature variations negligible, and the lines accurately identified. The instrumental adjustments were always made with the great care requisite in velocity measurements, and the measured and computed velocities of planets were compared from time to time. Some of these check results will be given in subsequent papers of this series.

MEASUREMENT AND REDUCTION OF THE PHOTOGRAPHS.

The photographs are measured on a Zeiss comparator, which has proved itself to be admirably adapted for work of this character. The essential parts of the instrument are two microscopes, rigidly supported at a fixed distance apart, and provided with micrometer eyepieces. The plate to be measured is fastened by spring clips to a sliding stage, to which the scale, engraved on silver, is also attached. The microscope used for viewing the plate is so arranged that the magnifying power can easily be varied from 13 to 25 diameters. In practice the lowest power is generally employed. The scale is divided to fifths of a millimeter, and thousandths of a millimeter can be read directly on the micrometer head, which is divided into 100 parts. Satisfactory means have been provided for illuminating both plate and scale. An examination of the scale made at the *Reichsanstalt* at Charlottenburg shows that its absolute errors probably do not exceed 2 μ. The errors of each division, considering the scale to be one of equal parts, are being determined here by Gill's method. A silver scale, inlaid in steel and divided to fifths of a millimeter, has been made in our instrument shop for the purpose of this comparison. The micrometer of the scale microscope has been tested for errors of run, and the corresponding corrections found to be negligible in measurements of these plates. A single narrow line, extending across the field of the viewing microscope, is ordinarily employed for the settings, though a double line can be used if desired. A slow-motion screw, which clamps to the stage, greatly facilitates the work of setting on the stellar lines.

The comparison spectrum, as already stated, is that of an induction spark taken in air between iron electrodes. Under these circumstances the air lines come out very strongly, but in most instances their hazy character unfits them for use as standards. In some portions of the spectrum, however, it has been necessary to employ the sharper air lines, because of the absence of iron lines. As no published wave-lengths of the air lines could be found that were accurate enough for the purpose

Dr. Frank Schlesinger[1] was requested to photograph the iron spark spectrum with the concave grating of ten feet focus for the purpose of measuring the wave-lengths of both the air and iron lines. The results for iron were in good agreement with those obtained by Kayser and Runge.

Much time was devoted to an examination of various methods of reduction, with the purpose of selecting one well adapted for this particular work. The first determinations of wave-length were made graphically, from curves plotted on squared paper. The large scale of the curves involved the necessity of making them in sections, and difficulty was experienced in drawing curves which satisfactorily represented the observations. Accordingly the curves were drawn on a large blackboard, and much better results obtained. Although fairly good wave-length determinations were made in this way the method was not considered entirely satisfactory.

In order to obtain good results with a short curve an interpolating machine was devised, and constructed in our instrument shop. It consists of a cast-iron plate, with plane upper surface, on which a piece of thin sheet celluloid, large enough to include the curve, is fastened by metal clips. The plate is clamped to the bed of a Brown & Sharpe milling machine, on which it can be moved in two directions at right angles by means of screws with micrometer heads graduated to thousandths of an inch. The coördinates (scale reading and wave-length) of the standard lines are thus measured off, and the points plotted by means of a sharp steel pin held in a fixed position by a support firmly attached to the overhanging arm of the milling machine. After the points have been plotted a curve is drawn through them by means of the device shown in Plate V. A flexible strip of tempered steel, of U section, is mounted above the iron plate in such a way that it can be bent to any desired curvature by means of nine screws. A movable table, bearing a compound microscope with adjustable cross-hairs, and a steel graving tool with chisel edge, is brought against the steel strip. The graving tool

[1] At that time Volunteer Research Assistant at this Observatory.

having been drawn up out of action, the table is moved along in contact with the strip, which is adjusted by the screws until the residuals (the distances between the plotted points and the intersection of the cross-hairs) have been made as small as possible. The carriage is then turned through 180°, and a curve traced through the points by the aid of the graving tool, which has been so adjusted as to pass over the path previously traversed by the intersection of the cross-hairs. During this process the apparatus remains on the bed of the milling machine. In order to take out the wave-length corresponding to a given scale reading it is now only necessary to replace the steel pin with which the points were plotted by a second microscope, the cross-hairs of which have been made to coincide with a point marked by the pin (Fig. 2). When the scale coördinate has been set at the given value, the other screw is turned until the intersection of the cross-hairs coincides with the curve. The reading on the micrometer head then gives the desired wave-length. Errors in the screws of the milling machine can easily be determined by observations of a standard scale clamped to the bed. This method of determining wave-lengths proved to be satisfactory, and good results were obtained by its aid.

The publication of Hartmann's valuable interpolation formula[1]

$$\lambda = \lambda_0 + \frac{c}{(n - n_0)^a},$$

placed us in possession of a still more satisfactory means of reduction. In its approximate form

$$\lambda = \lambda_0 + \frac{c}{n - n_0}, \qquad (1)$$

where n is the scale reading of the line, and c, λ_0, and n_0 are constants, this formula satisfactorily represents the spectral region λ 5150–5900. Experience showed, however, that when the constants are determined from measures of only three standard lines, the sum of the squares of the residuals corresponding to other standard lines, whose wave-lengths have been computed from the

[1] This JOURNAL, **8**, 218, November 1898.

PLATE V.

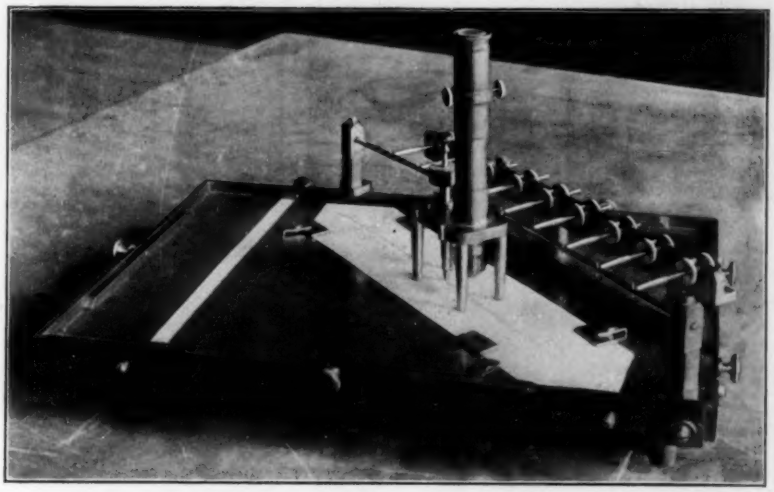


FIG. 1.—INTERPOLATING MACHINE ARRANGED FOR CURVE TRACING.

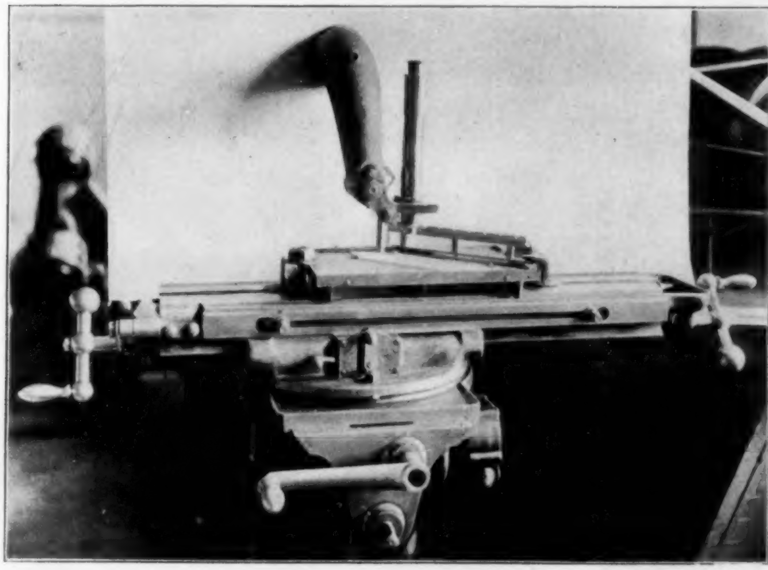


FIG. 2.—INTERPOLATING MACHINE ON BED OF MILLING MACHINE.

resulting expression, is sometimes much too large. This was found to be due, not to the inadequacy of the formula, but to the appearance of some of the standard lines on the stellar negatives. Any cause which produces lack of symmetry in a line tends to introduce an error into the determination of n. It was therefore decided to use a larger number of standard lines, and to make the reductions by the method of least squares.

From (1) we obtain observation equations of the form

$$\left.\begin{array}{l} n_1 = n_0 + \dfrac{c}{\lambda_1 - \lambda_0} \\ n_2 = n_0 + \dfrac{c}{\lambda_2 - \lambda_0} \\ \cdot \quad \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \quad \cdot \\ n_m = n_0 + \dfrac{c}{\lambda_m - \lambda_0} \end{array}\right\} \qquad (2)$$

Substituting in (1) values of n and λ corresponding to three standard lines, and solving, we obtain approximate values of the three constants, which will be called n_0', λ_0', and c'. The most probable values of n_0, λ_0 and c are $n_0 = n_0' + z_1$, $\lambda_0 = \lambda_0' + z_2$, $c = c' + z_3$, where z_1, z_2, z_3 are the corrections which are to be determined.

Substituting these quantities in the first observation equation and expanding by Taylor's theorem, we obtain

$$z_1 + \frac{c'}{(\lambda_1 - \lambda_0')^2} z_2 + \frac{1}{\lambda_1 - \lambda_0'} z_3 + m_1 = v_1 \qquad (3)$$

where $m_1 = \left(n_0' + \dfrac{c'}{\lambda_1 - \lambda_0'}\right) - n_1$. The coefficients of z_1, z_2, and z_3 are obtained by differentiating the first equation in (2) with respect to each of the variables, and substituting n_0', λ_0' and c' for n_0, λ_0 and c. Terms containing powers of z_1, z_2, z_3 higher than the first have been neglected.

If we now represent the coefficients of z_2 and z_3 by b_1 and c_1, and treat the other equations in (2) in the same way, our observation equations become

$$\left.\begin{array}{l} z_1 + b_1 z_2 + c_1 z_3 + m_1 = v_1 \\ z_1 + b_2 z_2 + c_2 z_3 + m_2 = v_2 \\ \quad - \quad - \quad - \quad - \\ \quad - \quad - \quad - \quad - \\ z_1 + b_m z_2 + c_m z_3 + m_m = v_m \end{array}\right\} \qquad (4)$$

Solution of the normal equations, which are formed from equations (4) in the ordinary way, gives the desired corrections z_1, z_2, z_3.

This method has proved very satisfactory in practice, and is employed in all of our wave-length determinations. The least squares solutions are greatly facilitated by the use of a *Brunsviga* calculating machine.[1]

In the measurement of the radial velocities of the brighter stars of the fourth type our endeavor has been to reduce each

[1] The method is similar to that given by Hartmann in a recent memoir (Potsdam Publications, Vol. XII, Appendix), which has reached us since the above was put in type. The following table of residuals, computed for nine standard iron lines on one of our negatives, gives a comparison of the results obtained with the approximate (H_1) and the rigorous (H_2) formulae, and illustrates the advantage of employing the method of least squares in both cases (H_1 corr. and H_2 corr.).

Line	Residuals			
	H_1	H_1 Corr.	H_2	H_2 Corr.
	Tenth-meters	Tenth-meters	Tenth-meters	Tenth-meters
10*	0.00	+0.05	+0.01	+0.12
12	— .25	— .19	— .26	— .15
15	— .19	— .11	— .20	— .10
17*	.00	+ .09	+ .01	+ .10
21	+ .09	+ .20	+ .10	+ .20
24	+ .04	+ .16	+ .06	+ .16
27	— .24	— .08	— .20	— .09
28	— .48	— .32	— .44	— .35
29*	.00	+ .19	.00	+ .10
[v v]	.396	.269	.355	.263
Constants				
n_0	—8333	—8339.8	—4372	—4368.7
λ_0	3065.75	3065.99	2828.57	2828.55
c	113,116,053	113,115,612	550,241,300	550,178,130

*Lines used in determining constants for H_1 and H_2.

plate independently of all others, and to avoid doubtful assumptions regarding the identification of stellar lines. The peculiar type of spectrum with which we are dealing makes this last point especially important. Comparisons of fourth type spectra with those of the third type[1] bring out very clearly the presence of strong iron lines, which are also conspicuous in the solar spectrum. These lines have been employed in the radial-velocity determinations. Some of them are not as susceptible of accurate measurement as other lines in their neighborhood, but it was thought better to employ them than to make unwarranted assumptions as to the origin of the latter lines.

The value of rV_s, the velocity in kilometers per second corresponding to a displacement of the lines equal to one division of the micrometer, is easily calculated.

$$V_s = \frac{\lambda}{299860}$$

gives the velocity in kilometers per second corresponding to a displacement of one tenth-meter.

From Hartmann's formula we have

$$n = n_0 + \frac{c}{\lambda - \lambda_0}.$$

Differentiating, we obtain

$$\frac{d\lambda}{dn} = \frac{(\lambda - \lambda_0)^2}{c}.$$

If dn = unity, the value of one division in tenth-meters is

$$d\lambda = \frac{(\lambda - \lambda_0)^2}{c}.$$

The values of the constants λ_0 and c are computed in the manner already described.

In the reductions we have used Campbell's expression[2]

$$v_d = -0.47 \sin t \cos \delta \cos \phi$$

for the correction due to the Earth's diurnal rotation, and Schlesinger's recently published formula[3]

$$[3.5392] \, (\Delta X \cos \alpha \cos \delta + \Delta Y \sin \alpha \cos \delta + \Delta Z \sin \delta)$$

[1] See Yerkes Observatory *Bulletin* No. 9.

[2] SCHEINER'S *Astronomical Spectroscopy*, Frost's translation, 341.

[3] This JOURNAL, 9, 159, March 1899.

for the correction due to the motion of the Earth in its orbit. Here $\Delta X, \Delta Y, \Delta Z$, are the components of the Earth's motion parallel to the line of equinoxes, parallel to the plane of the equator, and perpendicular to the plane of the equator respectively. They are tabulated in the Berlin *Jahrbuch* for every twelve hours in the year, and the values corresponding to the time of the observation can conveniently be taken out with the aid of the interpolation table given in Schlesinger's article. This method has the advantage of rendering unnecessary the calculation of the latitude and longitude of the star.

Although Ditscheiner's formula[1]

$$x = -\frac{(n^2 - l)\sin\frac{A}{2}}{nf\sqrt{l - n^2\sin^2\frac{A}{2}}}z^2$$

has been found to give the correction due to curvature of the spectral lines with a considerable degree of accuracy, it is often best in practice to determine the correction by actual measurement on a solar plate taken under similar conditions. Corrections for curvature have been applied in all cases where the accuracy of the wave-length determinations warranted.

BRIGHT LINES IN FOURTH TYPE SPECTRA.

We have already quoted Secchi's statement regarding the presence of bright lines in spectra of the fourth type. It is difficult to determine, however, from the conflicting evidence

found in Secchi's publications, whether he really saw the bright lines whose existence is shown by our photographs. The intensity curve of the spectrum of 78 *Schjellerup*,[2] which is reproduced herewith, favors the supposition that some of the lines were

[1] See Frost's *Scheiner*, p. 15.

[2] *Memoria Seconda*, p. 40. The red end of the spectrum is at the left.

actually seen, but if this was the case it is hard to understand why the most conspicuous of the bright lines, which falls near the head of the carbon absorption band in the yellow, was accorded so low an intensity, not exceeding that of its fainter companion toward the violet. Again, the illustration of the spectrum of the same star, published by Secchi in the second edition of *Le Soleil* (Plate M), contains no bright lines, while the drawing of the spectrum of 152 *Schjellerup* in the same plate shows several bright lines, though the most conspicuous of all are lacking. Secchi states that, in his opinion, the general appearance of the spectrum is that of a direct spectrum given by a gaseous body, rather than that of an absorption spectrum[1] though he reached no very definite conclusions regarding the physical condition of these stars.

In his memoir,[2] after pointing out the inconsistency of Secchi's statements, Dunér expresses the belief that the spectrum is simply one due to absorption. It will be seen later, however, that he has since observed one or two of the most conspicuous bright lines, which were not recorded by Secchi.

Our earliest photographs of these spectra, which were made in January 1898, seemed to leave little room for doubt as to the presence of bright lines. In view of Dunér's opinion, which was supported by the results of Vogel's observations, it was nevertheless deemed necessary to undertake a series of tests for the purpose of meeting any doubts that might arise.

The problem is to distinguish between true bright lines and bright spaces in a continuous spectrum bounded by dark lines or bands.

At the outset let us direct our attention to the apparent bright line at λ 5592 (Plate VI), returning later to a consideration of other similar lines.

1. This line is much brighter than the spectrum on either side of it. An exposure of four minutes is sufficient to photograph the line with a dispersion of three prisms, while equal

[1] *Le Soleil*, II, 458.

[2] *Loc. cit.*, 10.

density of the contiguous spectrum cannot be obtained under the same conditions with an exposure of less than about 12 to 15 minutes. If the line is supposed to be due to the continuous spectrum, it must be assumed that the carbon absorption band is interrupted at this point.

2. If the line were merely a section of the continuous spectrum, bounded by portions of the carbon absorption band, it should become less conspicuous as the dispersion is increased. Our experiments show the reverse to be true. Dispersions varying from that of a small direct-vision spectroscope to that of three heavy flint prisms were tried both visually and photographically. In all cases it was found that the contrast between the line and the contiguous spectrum increased rather than diminished with the dispersion.

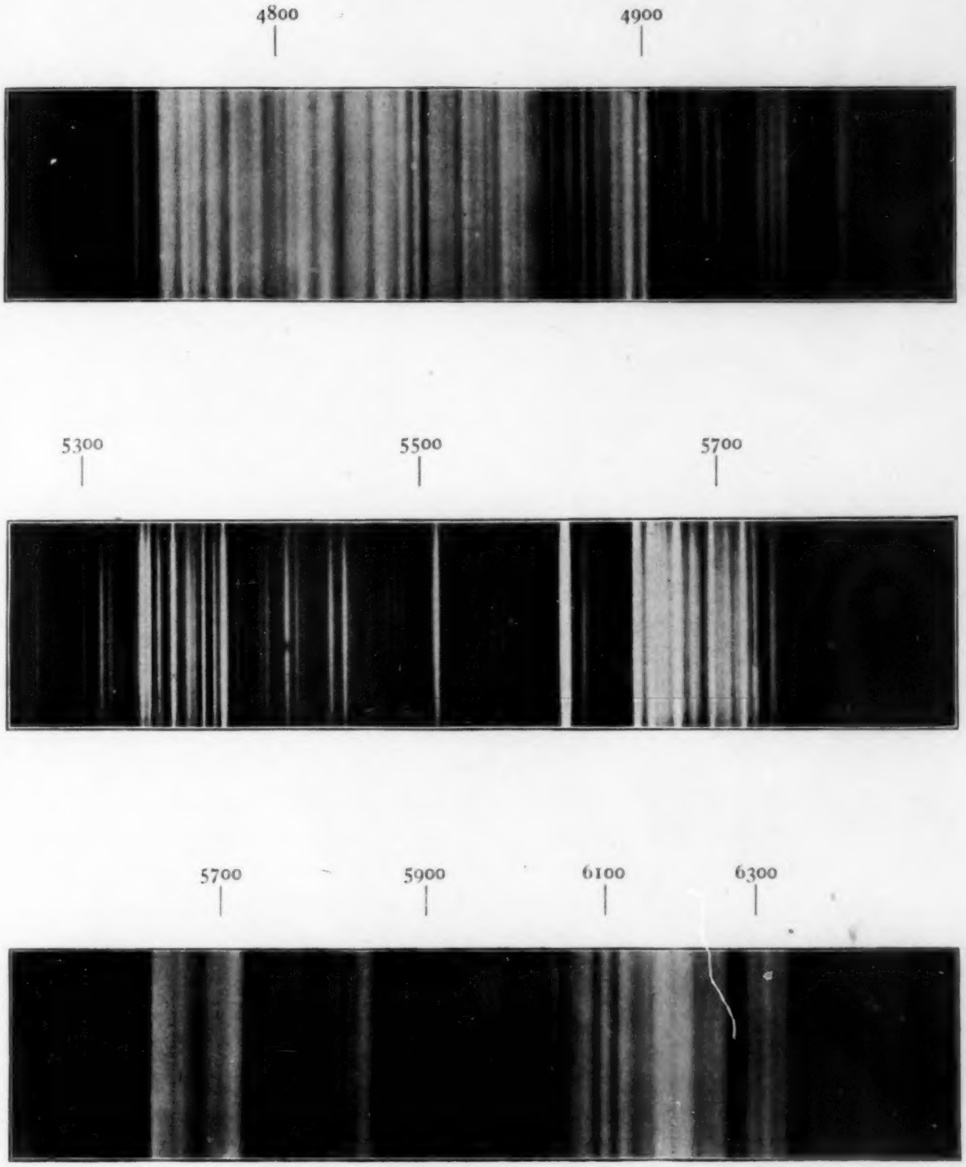
3. A bright section of the continuous spectrum would appear with less contrast as the slit was widened. Photographs taken with increasing slit-widths show no decrease in contrast, some of the best results having been obtained with the widest slits.

The conclusions based upon a study of the photographs are confirmed by visual observations. The spectra of 132 *Schjellerup* and 152 *Schjellerup* have been observed on several occasions with the three-prism spectroscope attached to the 40-inch telescope. The observing telescope employed has a focal length of 253 mm, and the eyepiece gave a magnification of 13 diameters. The bright line at λ 5592 was easily seen, as well as a number of other bright lines in the red, yellow, green, and blue.

At our request the spectrum of 152 *Schjellerup* has been examined with the 36-inch refractor of the Lick Observatory by Professors Keeler and Campbell. A dispersion of three prisms was employed. Professor Keeler describes the observations as follows:

"I compared the spectrum with Vogel's drawing in Potsdam Publications, Vol. IV. The drawing seemed to be merely a rough indication of what the spectrum actually is. What we saw was much more like your photograph. It is curious that Vogel did not see the bright line λ 550 $\pm$, as it is a conspicuous feature of

PLATE VI.



Bright Lines in the Spectrum of 152 Schjellerup.

the spectrum with the 36-inch. The bright block $\lambda 553 - \lambda 584$ seems to be a complex of bright and dark lines or bands, and the dark band as shown in the drawing ($\lambda 573$) is relatively too conspicuous. Vogel's dark band at $\lambda 525$ is made up of lines of which there are many in the neighborhood. There is a strong line at or near D. We tried to identify it with the Na line in a spirit lamp, but the telescope was jumping in a high wind, and the comparison did not amount to much. There were many dark lines in the red.

"To my mind, there is little doubt that the spectrum of this star contains bright lines."

In an article published in a recent number of this JOURNAL (March 1899), Dunér describes his own observations of bright lines in the spectra of several stars of the fourth type, which he has been able to see with the aid of the 36 cm Steinheil refractor of the Upsala Observatory, in spite of their invisibility with the smaller instrument at Lund.

It therefore seems safe to affirm that the spectrum of 152 *Schjellerup*, as well as the spectra of many other stars of the fourth type, contain several bright lines. The elevenfold enlargements from our negatives, which are reproduced in Plate VI, will serve to give an idea of the appearance of some of these lines in the spectrum of the star just named.[1] Some of the brightest of the lines are in the region between *Ha* and *D*, which is not shown to advantage in the plate, owing to the fact that the only photograph of this part of the spectrum hitherto made was taken with a rather inefficient optical combination (one prism and 508 mm camera). The photographs of the more refrangible regions were made with three prisms and the 271 mm camera, and are much more satisfactory. The less refrangible part of the bright zone in the yellow should be much brighter than it appears in the plate, the photograph having suffered from the rapid drop in the sensitiveness of isochromatic plates just at this

[1] These photographs have not been retouched, but the contrast of the one covering region λ 5300 — 5700 was increased photographically in enlarging the original negative.

point. Many of the apparent bright lines in the more refrangible part of the zone we have taken to be true bright lines, after much study of the photographs. In addition to the bright lines which fall upon the yellow carbon band, there is a fine group in the green. There is room for doubt as to the true character of some of the apparent bright lines in the blue, and, in certain cases, both here and in the less refrangible region, we have thought it best to measure both the dark and bright spaces, leaving the matter to be decided in the light of future work.

Although we do not desire, at the present time, to enter into a discussion of the physical condition of fourth type stars, a single inference may be drawn from the appearance of such a line as that at $\lambda 5592$ in the spectrum of 152 *Schjellerup*. It would seem probable that the substance to which this line is due must exist in the star's atmosphere at a level above that of the carbon or hydrocarbon vapor which produces the heavy absorption bands. The case is apparently analogous to that of the Sun's atmosphere, where the hydrogen and calcium extend above the layer of carbon vapor. As one of us has recently shown, this layer is extremely thin, and lies at the base of the chromosphere.[1]

THE UNIVERSITY OF CHICAGO,
Yerkes Observatory, May 4, 1899.

[1] GEORGE E. HALE, "On the Presence of Carbon in the Chromosphere," this JOURNAL, **6**, 412, December 1897.

ON THE INTERPRETATION OF THE TYPICAL SPECTRUM OF THE NEW STARS.[1]

By J. WILSING.

THE most striking phenomenon in the spectrum of Nova Aurigae (1892) was the occurrence of pairs of lines, consisting each of a bright line with an absorption line at its more refrangible edge. In view of the extensive and successful applications of Doppler's principle to astronomical problems which were being made just at that time, it was natural to explain the relative displacement by corresponding motions in the line of sight, and all of the hypotheses proposed at that time as to the nature of the new stars were based on the application of Doppler's principle. Great difficulties were presented, however, by the resulting extraordinary relative velocities in the line of sight of 1000 to 1500 kilometers, and the suspicion already existing, as to whether Doppler's principle was admissible in explaining the double spectrum, continually increased as no appreciable changes in the relative position of the double lines could be perceived during several months; this was especially the case when in the spectrum of Nova Normae (1893) the components of the pairs of bright and dark lines were also displaced in the same direction as in case of Nova Aurigae. Since, further, two other objects, β Lyrae and *P* Cygni (the Nova of 1600), also exhibited the typical spectrum of the temporary stars, in the first case mixed in with displacements of the lines which could be accounted for on Doppler's principle by orbital motion, an accidental occurrence of displacements in the same direction seemed highly improbable, and attempts accordingly had to be made to find another explanation.

Observations of different sorts on changes in the wave-lengths of spectral lines which are not to be attributed to motions are

[1] *Sitzungsberichte der k. Akademie der Wissenschaften zu Berlin.* Session of the physical-mathematical section on May 4, 1899.

available. First in the case of fluorescing bodies changes of wave-length occur, the bright bands being for the most part less refrangible than the corresponding absorption band, and being displaced with different concentration. According to E. Wiedemann and G. C. Schmidt[1] this is a rule for all luminescence phenomena in which the light is developed at low temperatures.

But double spectra can also be produced within the range of validity of Kirchhoff's law by superposition of different masses of hot gas. According to Paschen's[2] bolometric measures the emission bands of carbonic acid are displaced toward the red with rising temperature. If the hot gases were placed between the spectroscope slit and a source of light giving a continuous spectrum of less intensity, the cooler carbonic acid, mixed with the air, absorbed, on the way from the slit to the bolometer, a group of rays which lay on the more refrangible edge of the emission band of the heated carbonic acid.

The investigations of W. J. Humphreys and J. F. Mohler[3] are of special importance in the physical explanation of double spectra. They were the first to notice slight displacements of lines in the visual and ultra-violet part of the arc-spectrum of the metals as they raised to twelve atmospheres the pressure in the enclosure about the arc. The lines always moved toward the less refrangible end of the spectrum with increasing pressure, and it was found that the amount of the displacement was in general proportional to the pressure, and to the wave-length of the line, but varied for the lines of different metals, and for different series of lines of the same metal. The increase of wave-length for a pressure of twelve atmospheres indeed hardly reached 0.05 tenth-meters, so that the employment of very

[1] "Zur Mechanik des Leuchtens," *Wied. Ann.*, **37**, 177; "Fluorescenz des Natrium- und Kaliumdampfes," *Wied. Ann.*, **57**, —; "Ueber Lichtemission organischer Substanzen in gasförmigem, flüssigem und festem Zustand," *Wied. Ann.*, **56**, 18.

[2] "Ueber die Emission der Gase," *Wied. Ann.*, **51**, 1; "Bolometrische Arbeiten," *Wied. Ann.*, **53**, 287.

[3] "Effect of pressure on wave-lengths of lines in the arc-spectra of certain elements," this JOURNAL, **3**, **4**, **5**, **6**.

powerful dispersion was necessary to establish so slight a displacement.

Larger displacements, similarly in the direction of increasing wave-lengths, were found by Eder and Valenta[1] in the spectrum of argon and of sulphur by raising the pressure and employing the spark. The shifts of the sulphur lines amounted here to about 0.5 t.m., and those of the argon lines in some cases even reached 1 tenth-meter, being accompanied by much broadening and diffuseness.

The small displacements (averaging 0.4 t.m.) observed by Ebert[2] in the flame spectra of the easily volatile metallic salts on increasing the amount of vapor are attributed by him to an unsymmetrical broadening of the lines toward the red. Gouy[3] similarly noticed shifts of certain definite lines in the spectrum of sodium and sulphur which he vaporized in the arc. But here also the possibility of a rise of pressure in consequence of violent vaporization cannot be excluded.

The observations last cited suggest the direction which must be taken in the experiments for producing shifts of lines without motion in the sight-line, and ultimately for producing double spectra. It therefore becomes the problem to increase the magnitude of the displacement so that it may be of the same order as that in the double spectrum of Nova Aurigae, in which the relative displacement of the bright and dark lines amounted to from 10 to 20 tenth-meters.[4]

According to the observations of Humphreys and Mohler this should be attained by continued increase of pressure up to several hundred atmospheres. In seeking to avoid the experimental difficulties connected with so great a rise of pressure the

[1] "Spectralanalytische Untersuchung des Argons." "Die Spectren des Schwefels." *Denkschriften der k. Akad. der Wiss. zu Wien.*, **64, 67**.

[2] "Die Methode der hohen Interferenzen in ihrer Verwendbarkeit für Zwecke der quantitativen Spectralanalyse." *Wied. Ann.*, **34**.

[3] "Sur l'élargissement des raies spectrales des métaux." *C. R.*, **108**.

[4] H. C. VOGEL, Uebe den neuen Stern im Fuhrmann. *Abhandlungen der k. Akad. der Wiss. zu Berlin 1893*.

idea occurred to me of investigating the spectra of spark discharges in liquids in which it is known that very high tensions arise.

Masson[1] early investigated the spectra of the discharge from condensers and of the arc in various liquids, but he found bright lines only in the arc with the use of metallic electrodes. Later Planté, Righi, Slouguinoff, and others studied the optical phenomena attending the discharges in liquids, but without going into the subject of the spectrum. But in the spectrum of the arc passing between platinum and silver electrodes in solutions of salts of sodium and lithium, Colley[2] found, beside the hydrogen lines, several lines of these metals, and also a series of platinum lines. Similarly Liveing and Dewar[3] observed lines due to the platinum electrodes in the spectrum of the spark discharge in liquid gases and air. A more accurate investigation of the lines in respect to position and appearance has, however, not yet been carried out.

I employed in my experiments a large inductorium, in the secondary circuit of which a spark-gap was inserted before the electrodes in the usual way in addition to the battery. With the passage of each spark a blinding discharge took place between the electrodes in the water, giving a very intense continuous spectrum crossed by faint lines. As the brightness of the continuous background and the flickering due to the irregularity of the discharge hindered the direct visual measurement of the lines, I photographed the discharge spectra in water and air on the same plate with a spectrograph, thus rendering possible a convenient and accurate determination of the relative position of the systems of lines of the two spectra. The length of the prismatic spectrum between λ 4800 and λ 4600 was about 50 mm, and the wave-lengths of sharp lines could be determined within a few hundredths of a tenth-meter. Beside this, Professor

[1] "Études de photométrie électrique." *Ann. de Chim. et de Phys.*, **31**, 1851.

[2] *Journal de Physique*, Ser. 1, 9.

[3] "Preliminary note on the spectrum of the electric discharge in liquid oxygen, air, and nitrogen." *Phil. Mag.*, **38**, 1894.

Lohse and Dr. Hartmann were kind enough to make me several plates with a grating spectrograph of high dispersion, and with a large prism spectrograph.

I have investigated the spectrum of the discharge in water of iron, nickel, platinum, copper, tin, zinc, cadmium, lead, and silver. In the spectrum of iron numerous pairs, consisting of a bright and a dark line, appear, the bright component being displaced considerably toward the less refrangible end of the spectrum, while the absorption lines suffer an appreciable displacement toward the red in only a few instances. Fine maxima of intensity can also be recognized in a few of the bright lines. There are, moreover, isolated bright lines which are similarly displaced appreciably toward the red. The lines are quite faint and hazy on the less refrangible edge. In the following table column 1 contains the wave-lengths of the lines whose displacement was measured; in column 2, E and A denote, respectively, emission and absorption lines; the displacements measured on different plates are given in the following columns, plus denoting displacements toward the red, and minus toward the violet; the last column contains remarks as to the appearance of the lines.

The increase of wave-length is largest for the lines which are bounded by absorption lines on the violet side. But here the measurement probably gives too large values to the displacement,[1] for if two strata of vapor are present in the neighborhood of the electrodes, the inner and hotter of which gives broadened and displaced lines, while the outer and cooler gives a normal spectrum with narrow lines, then the portion of the bright lines lying toward the violet must be neutralized by the absorption of the cooler vapor, and there remains only the portion on the less refrangible side of the absorption line caused by the broadening. A setting on the middle of the bright line therefore necessarily gives too large a displacement. Direct observation shows, however, that very often the emission and

[1] EDER und VALENTA, "Ueber den Funkenspectrum des Calciums und Lithiums und seine Verbreiterungs- und Umkehrungserscheinungen." *Denkschriften der Kais. Akad. Wien.*, 67, 8, 1898.

IRON.

Kayser and Runge	Kind of line	Plate 1	Plate 2	Plate 3	Remarks
Tenth-meters		Tenth-meters	Tenth-meters	Tenth-meters	
3737.27	A	+0.03			
	E	+1.12			
3749.61	A	—0.09			
	E	+0.81			
3765.66	E	+0.13			
3767.31	A	—0.05			
	E	+0.17			
3797.65	E	+0.17	+0.28		
3813.12	A	—0.20			
	E	+0.07			
3815.97	A	—0.07	—0.22		
	E	+0.51	+1.12		Very distinct
3820.56	A	—0.20		+0.10	
	E	+0.93		+0.90	Very distinct
3827.96	A	—0.10	—0.16	0.00	
	E	+0.92	+0.106	+0.76	
3834.37	A	—0.07			
	E	+0.36			
3841.19	A	—0.08		0.00	
	E	+0.43	+0.58	+0.54	Distinct
3843.40	E	0.00		+0.08	
3846.96	E	+0.24			
3850.11	E	+0.32			
3860.03	A	—0.07			
	E	+0.95			
3865.65	E	+0.32			
3888.63	E	+0.40		+0.38	
3903.06	E	+0.34			
4071.79	A			+0.11	Sharply bounded; distinctly displaced
4107.58	E			+0.20	
4109.88	E			+0.22	
4118.62	E			+0.22	Very distinct; sharply bounded
4132.15	E			+0.33	
4181.85	E			+0.22	Weak, but distinct
4199.19	E			+0.16	Weak, but distinct
4260.64	E	+1.00			Very distinct
4271.30	A	—0.05			
4271.93	E	+0.76			Sharply bounded maximum of intensity
4307.96	A	—0.05			
	E	+1.12			Sharply bounded maximum of intensity
4383.70	A	0.00			
	E	+1.33			

NICKEL.

Hasselberg	Kind of line	Plate 1	Plate 2	Remarks
Tenth-meters		Tenth-met'rs	Tenth-met'rs	
3807.30	A	+0.01	—0.06	Faint
	E	+0.36	+0.43	
3858.40	A	+0.01	—0.07	Very distinct
	E	+0.39	+0.38	Edges of a strong band, diffuse on the red side
		+2.09	+1.70	
4401.70	E	+0.19	0.00	Edges of a diffuse band
		+4.08	+3.53	
4459.21	E	+0.19		Edges of a sharply-bounded band
		+5.82		

COPPER.

Kayser and Runge	Kind of line	Plate 1	Remarks
Tenth-meters		Tenth-met'rs	
4275.32	E	—0.05	Edges of a strong band sharply bounded on both sides
		+3.83	
4378.40	E	—0.10	Edges of a strong band sharply bounded on both sides
		+2.94	
4539.98	E	—0.43	Edges rather weak, more sharply bounded toward violet
		+5.10	
4587.19	E	—0.44	Edges more sharply bounded toward violet
		+5.01	
4651.31	E	—0.01	Edges of a band sharply bounded on both sides
		+3.93	

ZINC.

Kayser and Runge	Kind of line	Plate 1	Remarks
Tenth-meters		Tenth-met'rs	
4680.38	E	+0.64	Edges of a bright band, sharper toward violet
		+7.31	
4722.26	E	+1.43	Edges of a band, sharp toward violet, very diffuse toward red
		+13.20	
4810.71	A	—0.05	Edges of a strong absorption line
		+1.71	
		+1.71	Edges of a bright band, diffuse toward red
		+8.08	

TIN.

Kayser and Runge	Kind of line	Plate 1	Plate 2	Remarks
Tenth-meters		Tenth-met'rs	Tenth-met'rs	
3801.16	A	—0.07	+0.01	Sharply bounded
	E	+0.50	+0.93	Edges of a very faint band
		+5.52	+4.14	
4524.92	E	—0.26	—0.10	Very faint band, not sharp
		+4.84	+5.78	

CADMIUM.

Kayser and Runge	Kind of line	Plate 1	Plate 2	Remarks
Tenth-meters		Tenth-met'rs	Tenth-met'rs	
4413.23	E	—1.40	—0.99	Edges of a diffuse band
		+1.17	+0.88	
4678.37	E	—0.10	—0.10	Edges of a band sharp toward violet, diffuse toward red
		+8.19	+11.01	
4800.09	E	+1.52	+1.49	Edges of a band sharp toward violet, diffuse toward red
		+8.40	+8.17	

absorption spectra change places with each other, varying according to the intensity of the discharge and of the development of vapors at the electrodes, so that the two spectra overlie each other in the image.

In the spectrum of nickel a very distinct double line appears at λ 3858.40; the bright lines are broader and are more displaced toward the red than in the iron spectrum.

Aside from a slight diffuseness no appreciable displacements could be recognized in the spectrum of the discharge between platinum electrodes and water.

But the bright lines in the spectrum of copper become broad bands, and in the case of tin, zinc, and cadmium gain still more and are so greatly displaced that they can be easily perceived without magnification. It should be particularly mentioned that the more refrangible edge of the individual bands is so strongly shifted toward the red that it lies entirely beyond the corresponding line in the normal spectrum. Narrow maxima of

intensity sometimes appear within the bright bands. The bands are sharply bounded toward the violet, but more or less diffuse toward the red. Still there is on the less refrangible side, especially in the bands of the copper spectrum, a distinct boundary where the intensity on the otherwise uniformly bright band rapidly falls off. Sharply bounded absorption lines, such as in iron and zinc, were not present in the portion investigated of the spectrum of copper and cadmium, but in the zinc spectrum there is a strong absorption line with an appreciable displacement toward the red. It is remarkable that the strong cadmium line at λ 4413.23 is not displaced, being only symmetrically broadened.

Nothing could be seen of the fine lines in the silver spectrum on the discharge in water, the spectrum being entirely continuous.

In the spectrum of magnesium there appeared in place of the triplets

$$\lambda\, 3829.51,\ \lambda\, 3832.46,\ \lambda\, 3838.44$$

some very diffuse absorption lines without appreciable displacement; at 4481.4 an extremely broad and dim emission band could be perceived on some of the plates without using any magnifying power, the middle of which, however, coincides with the corresponding line in the normal spectrum. For magnesium I have also investigated the less refrangible portion of the spectrum. On direct examination of the spectrum the *b* lines appeared sometimes dark and sometimes they disappeared entirely and were replaced by a very broad and bright band, diffuse toward the red, the violet edge of which is more refrangible than b_4. This band, which also appears simultaneously with the absorption lines, can readily be perceived on the spectrograms, and, since it shows no trace of resolution into single lines, probably is not identical with the bands at λ 518 $\mu\mu$ and 521 $\mu\mu$, observed by Liveing and Dewar[1] in the magnesium spectrum when in the presence of hydrogen, since the latter bands are resolvable and shaded off toward the violet. Moreover,

[1] "Investigations on the spectrum of magnesium." *Proc. R. S.*, 32 and 34.

the more refrangible bands of the magnesium-hydrogen spectrum at λ 480 and 485 $\mu\mu$ are lacking on the plates. But there is a fine absorption line present at λ 521 $\mu\mu$ which coincides with the edge of a magnesium-hydrogen band. The bands of magnesium oxide at λ 4995.6 and 5006.4 are faintly indicated.

In the spectrum of lead a broad, faint absorption line is visible at λ 4058.0; at λ 4245.3 and λ 4386.4 there also occur extremely broad, faint and diffuse bright bands which extend from the place of the line in the normal spectrum toward the red.

The magnitude of the displacement and the broadening of the metallic lines is, indeed, of a similar order in case of the different plates, but noticeable differences nevertheless occur, which are in part to be attributed to the different duration of exposure and development of plates, but chiefly to the varying intensity of the discharge, which changes with the strength of the current and the distance of the electrodes. Before deciding the question of what influence the molecular forces acting between the particles of vapor and liquid would have on the appearance of the spectrum it is necessary to compare the discharge in different liquids. I have investigated the spectra of the discharges between iron electrodes in water and in alcohol only, and have found no appreciable differences; on employing oils the liquid was quickly clouded by decomposition and union with the substance of the electrodes, so that it is not possible to obtain a plate of the spectra without special arrangements.

A comparison of the displacements of the lines for the different metals shows, in agreement with the following measures of Humphreys and Mohler, that they are considerably greater in the spectrum of tin, zinc, and particularly cadmium, than for iron and platinum.

DISPLACEMENTS AT A PRESSURE OF 12 ATMOSPHERES.[1]

Platinum,	0.020	Copper,	0.033	Zinc,	0.057
Iron,	0.025	Tin,	0.055	Cadmium,	0.080
Nickel,	0.028				

If we assume with Humphreys and Mohler a proportionality between pressure and displacement, then the pressure which the volatile gases undergo on the discharge in water must amount to several hundred atmospheres.

In the metallic spectra obtained in the manner described above there now occur displacements of lines and double lines which are in every respect similar to those in the spectra of Nova Aurigae. In the spectrum of that star the middle of the much broadened bright lines, sharply bounded toward the violet and diffuse toward the red, were considerably displaced toward the less refrangible end of the spectrum. Occasionally quite sharp maxima of intensity appeared in the bright lines in the star's spectrum, just as was observed in the artificial spectra in some cases. We can therefore imagine the star's spectrum to have originated in the superposition of the absorption spectrum, as it indicates a slight vapor pressure, the dark lines being partially brightened by the bright and much broadened and displaced lines, and thus undergoing an apparent displacement toward the violet.

The fact that in the spectrum of the Nova the duplicity was especially marked in the case of the hydrogen lines is not contradictory to the assumption that the luminous gases in the photosphere were under considerable pressure. Since a long series of experiments, of which I shall report in full in another place, gave the result that the hydrogen spectrum will become continuous by broadening of the lines with increase of pressure, when at the same time the potential and the temperature of the discharge increases, as is the case in Geissler tubes, with a fixed distance of the electrodes. If, however, the induction current passes through the tube without a jar by a sufficient decrease of

[1] This JOURNAL, 3, 135, 1896.

the distance of the electrodes, there appears between the electrodes white phosphorescence which, even at an atmospheric pressure, displays the lines of the hydrogen spectrum with the same degree of sharpness as with the pressure of a few millimeters. The assumption that the hydrogen lines undergo similar displacements to the metallic and argon lines on increase of pressure might therefore be permissible, and I hope soon to be able to make the necessary experiments on this subject. In view of the tendency of the hydrogen lines to broaden with increasing pressure we must assume that the temperature in the photosphere of the Nova was relatively slight.

With the great accuracy which the determination of the displacements of lines in stellar spectra for purposes of measuring the velocity has reached, the changes of wave-lengths by pressure can no longer be neglected. In a comparison of the wave-lengths of Rowland's solar spectrum with the wave-lengths of the corresponding metallic lines it is true that Jewell[1] has found only a relative displacement of the two systems of from 0.01 to 0.02 tenth-meters, which corresponds to a pressure of a very few atmospheres, and the pressure in the photosphere of the stars in general can hardly be assumed to be higher. If, however, quantities of this order are to be taken into account in measurements of velocity whose accuracy is within a kilometer, then it is only necessary to determine the difference of the displacements dependent alone upon the pressure in the photosphere, for two lines whose displacement for an increase of pressure of one atmosphere are known. If we denote by p the pressure, by v and V the radial velocity of the star in the line of sight and the velocity of light, by a and a_1 two constants, and by l_1 and l_2 the measured displacements, we shall have

$$p\,a_1 + \frac{\lambda_1 v}{V} = l_1,$$

and

$$p\,a_2 + \frac{\lambda_2 v}{V} = l_2,$$

[1] "The Coincidence of Solar and Metallic Lines." This JOURNAL, 3, 1896.

whence $$v = V\frac{a_2 l_1 - a_1 l_2}{a_2 \lambda_1 - a_1 \lambda_2}.$$

In order to be able to calculate the velocity v of the motion in the line of sight it is necessary only to know the ratio $\frac{a_1}{a_2}$. This ratio could be directly determined for lines of different metals by measurements of the displacements which these lines undergo in the spectrum of the discharge in liquids, if alloys of the metals were employed as electrodes, since in this case the pressure would probably be the same for both metals.

Minor Contributions and Notes

THE NEW ALGOL VARIABLE IN CYGNUS.[1] +45° 3062.

An announcement is made in the *Astronomische Nachrichten*, **149**, 271, that the star $+45°$ 3062, R.A. $= 20^h\ 2.4^m$, Dec. $= +45°\ 53'$ (1855), mag. 8.6, is a variable star of the Algol type. Mme. L. Ceraski, of Moscow, found it abnormally faint on a photographic plate taken on May 20, 1898, and M. S. Blajko, after observing it visually for a long time, found it again at minimum on May 7, 1899. An examination was accordingly made of the Draper Memorial photographs to determine the nature of the variation. The region was covered by 195 plates, 170 of which showed the star at its full brightness, including 28 taken in 1890, 18 in 1891, 22 in 1892, 17 in 1893, 13 in 1894, 17 in 1895, 21 in 1896, 17 in 1897, 12 in 1898, and 5 in 1899. Besides these, twenty plates show the star when it was below its normal brightness. From a discussion of these plates it appears that the minima they indicate, as well as the two minima found at Moscow, may be closely represented by the formula *J.D.* $2{,}411{,}343.605^d + 4.57294^d\ E$. The period, therefore, is $4^d\ 13^h\ 45^m\ 2^s$, with an uncertainty which probably does not exceed one or two seconds. The variation in brightness of this star amounts to about three magnitudes, and, therefore, exceeds that of any Algol star hitherto discovered. Like all other Algol stars, its spectrum is of the first type.

The announcement of the discovery of this variable reached this Observatory on June 1. On June 3, the elements and ephemeris had been determined just in time to prepare for the minimum of that night. Accordingly, the star was followed all night by Professor Wendell, assisted by Mr. Leon Campbell, and 272 settings were made with the photometer attached to the 15-inch equatorial. From these it appears that at 16.0^h G. M. T., it was 0.20 magnitude brighter than the comparison star, $+45°$ 3067, while at 19.9^h G. M. T., when observations were stopped by the dawn, it was 2.25 magnitudes fainter than the same comparison star, although it was still 1.5^h before the predicted minimum. Observations by Argelander's method were also made all night

[1] *Harvard College Observatory Circular* No. 44.

by Mr. Wm. M. Reed, with the 6-inch equatorial. Meanwhile, thirty photographic images were obtained by Mr. H. R. Colson, assisted by Mr. E. R. Cram.

The minima so far observed are given in chronological order in the following table, including, on June 3 and 8, only the photographs taken with the 8-inch Draper telescope. The value of E is given in the first column. The second column gives the designation of the plate, A denoting the 24-inch Bruce telescope, B the 8-inch Bache telescope, and I the 8-inch Draper telescope. B 1719, I 231, I 907, I 1303, I 3719, I 7744, and I 11504 are spectrum plates. The date on which the photograph was taken, the Greenwich Mean Time, the Julian Day omitting the three left hand figures, 241, and the fraction of a day following Greenwich Mean Noon, and the length of exposure, are given in the next four columns. The photographic magnitude is given in the seventh column, the computed time of minimum in the eighth, and the observed minus the computed in the ninth column. The tenth column gives a correction for the magnitude of the star derived from the figures given in the seventh and ninth columns. The sign is indeterminate, and corresponds with the assumption that the period is uniform. The corrected residuals are given in the eleventh column. No correction has been applied for the light equation. The error from this cause is small, since the star is not very far from the pole of the ecliptic. The last column gives the error in the observed magnitude assuming the computed magnitude to be correct.

OBSERVED MINIMA.

E	Plate	Date	G.M.T.	J. D.	Ex.	Mag.	Comp.	O-C	Corr.	O-C'	Err.
		y m d	h m	d	m			d	d	d	
—176	B 1719	1887 9 23	13 10	0538.549	70	<9.1	0538.768	—.219	......	......	.....
0	I 231	1889 12 6	11 28	1343.478	113	9.83	1343.605	—.127	+.132	+.005	—.03
+ 25	I 907	1890 3 30	20 49	1457.867	87	<9.9	1457.928	—.061	......	......	.....
42	I 1303	1890 6 16	17 41	1535.737	75	<9.9	1535.668	+.069	.....	......	.....
52	I 1540	1890 8 1	14 38	1581.610	13	9.17	1581.398	+.212	—.224	—.012	—.06
59	I 1777	1890 9 2	14 48	1613.617	13	9.27	1613.408	+.209	—.203	+.006	+.03
121	I 3719	1891 6 12	18 57	1896.790	60	9.90	1896.931	—.141	+.126	—.015	+.21
244	I 7744	1892 12 26	12 44	2459.531	59	9.89	2459.402	+.129	—.126	+.003	+.05
297	I 9300	1893 8 25	13 53	2701.578	11	9.32	2701.768	—.190	+.191	+.001	.00
351	A 582	1894 4 29	20 10	2948.840	12	9.92	2948.707	+.133	—.125	+.008	+.11
384	I 11504	1894 9 27	13 37	3099.567	70	<10.2	3099.614	—.047	......	......	.....
387	I 11585	1894 10 11	13 1	3113.542	11	9.17	3113.333	+.209	—.224	—.015	—.08
471	I 13759	1895 10 30	13 47	3497.574	10	10.21	3497.460	+.114	—.113	+.001	+.06
503	I 14711	1896 3 24	19 30	3643.812	26	11.78	3643.794	+.018	—.031	—.013	—.01
517	I 15182	1896 5 27	16 43	3707.697	12	10.11	3707.815	—.118	+.116	—.002	+.03
522	I 15328	1896 6 19	17 30	3730.729	11	11.68	3730.680	+.049	—.047	+.002	.00

E	Plate	Date			G. M. T.		J. D.	Ex.	Mag.	Comp.	O-C	Corr.	O-C′	Err.
		y	m	d	h	m	d	m		d	d	d	d	
+543	I 16009	1896	9	23	16	19	3826.680	13	11.88	3826.711	—.031	+.010	—.021	+.09
555	I 16569	1896	11	17	10	39	3881.444	11	9.61	3881.587	—.143	+.149	+.006	—.07
632	I 19445	1897	11	4	13	10	4233.549	11	9.72	4233.703	—.154	+.139	—.015	+.16
675	......	1898	5	20	.....		4430.4	..	.....	4430.339	+.061	......	......	.....
749	I 22770	1899	4	23	20	14	4768.843	23	10.23	4768.737	+.106	—.112	—.005	—.15
752	......	1899	5	7	10	54	4782.446	..	.....	4782.456	—.010	......	......	.....
758	I 22981	1899	6	3	15	55	4809.663	10	9.22	4809.894	—.231	+.222	—.009	+.08
758	I 22982	1899	6	3	16	57	4809.706	11	9.60	4809.894	—.188	+.151	—.037	+.01
758	I 22986	1899	6	3	19	40	4809.819	12	11.38	4809.894	—.075	+.067	—.008	+.20
758	I 22987	1899	6	3	20	6	4809.837	4	11.54	4809.894	—.057	+.057	.000	.00
758	I 22988	1899	6	3	20	13	4809.842	1	< 10.8	4809.894	—.052	......	......	.....
759	I 22995	1899	6	8	14	00	4814.583	13	9.95	4814.466	+.117	—.122	—.005	—.17
759	I 22996	1899	6	8	14	14	4814.593	10	9.85	4814.466	+.127	—.129	—.002	—.06
759	I 22997	1899	6	8	14	29	4814.603	15	9.88	4814.466	+.137	—.127	+.010	+.14
759	I 22998	1899	6	8	14	43	4814.613	10	9.58	4814.466	+.147	—.153	—.006	—.06
759	I 22999	1899	6	8	14	53	4814.620	10	9.55	4814.466	+.154	—.156	—.007	—.01
759	I 23000	1899	6	8	15	9	4814.631	19	9.55	4814.466	+.165	—.156	+.009	+.07
759	I 23003	1899	6	8	16	32	4814.689	14	9.22	4814 466	+.223	—.213	+.010	+.06

E 675. This is the date on which the plate was taken from which Madame Ceraski discovered the variable. The time is not given, but, owing to the northern latitude of Moscow, it has been assumed to be near midnight. As the brightness is not stated, no correction for magnitude can be applied.

E 752. Found by M. Blajko from visual observations.

E 758. The last plate, I 22988, was taken in strong twilight so that the Pole Star was barely visible. The plate was not fogged, but the star had become too faint to be photographed.

On five plates, taken at 0519.592, 1720.483, 1935.849, 3058.784, and 3859.525, the variable appears to be about two tenths of a magnitude below its maximum brightness, 8.96, but the phase shows that it was not at minimum. On a few plates the variable appears a little brighter than normal, but these small variations are probably due to photographic effects, such as distance from center of plate, or difference in color, which affects chart images differently from spectra.

The average value of the residuals in the last column is $\pm$ 0.07. It will, therefore, be seen that the formula given above serves to compute the magnitudes for the last ten years with such accuracy that they differ from the measured values on the average by less than a tenth of a magnitude. Even these small differences could doubtless be diminished by applying the correction for the light equation, by correcting

the light curve, since the positive residuals slightly exceed the negative, and by remeasuring the more discordant plates. In each of the five cases in which the star is not seen, indicated by the sign < followed by the magnitude of the faintest star visible on the plate, computation shows that the variable must have been fainter than this magnitude. An ephemeris for the remainder of the year is given below.

EPHEMERIS OF HELIOCENTRIC MINIMA.

E	J. D.	Min. 1899				E	J. D.	Min. 1899				E	J. D.	Min. 1899			
		m	d	h	m			m	d	h	m			m	d	h	m
758	4809.89352	6	3	21	26	774	4883.06056	8	16	1	28	790	4956.22760	10	28	5	28
759	4814.46646	6	8	11	11	775	4887.63350	8	20	15	12	791	4960.80054	11	1	19	13
760	4819.03940	6	13	0	56	776	4892.20644	8	25	4	57	792	4965.37348	11	6	8	57
761	4823.61234	6	17	14	41	777	4896.77938	8	29	18	42	793	4969.94642	11	10	22	42
762	4828.18528	6	22	4	26	778	4901.35232	9	3	8	27	794	4974.51936	11	15	12	27
763	4832.75822	6	26	18	11	779	4905.92526	9	7	22	12	795	4979.09230	11	20	2	12
764	4837.33116	7	1	7	56	780	4910.49820	9	12	11	58	796	4983.66524	11	24	15	57
765	4841.90410	7	5	21	42	781	4915.07114	9	17	1	42	797	4988.23818	11	29	5	43
766	4846.47704	7	10	11	27	782	4919.64408	9	21	15	27	798	4992.81112	12	3	19	28
767	4851.04998	7	15	1	12	783	4924.21702	9	26	5	12	799	4997.38406	12	8	9	13
768	4855.62292	7	19	14	57	784	4928.78996	9	30	18	57	800	5001.95700	12	12	22	58
769	4860.19586	7	24	4	42	785	4933.36290	10	5	8	43	801	5006.52994	12	17	12	43
770	4864.76880	7	28	18	27	786	4937.93584	10	9	22	28	802	5011.10288	12	22	2	28
771	4869.34174	8	2	8	12	787	4942.50878	10	14	12	13	803	5015.67582	12	26	16	13
772	4873.91468	8	6	21	57	788	4947.08172	10	19	1	58	804	5020.24876	12	31	5	58
773	4878.48762	8	11	11	43	789	4951.65466	10	23	15	43						

It will be noticed that nearly a year would have been saved had the original discovery of the variability of this star been sent here for confirmation from the photographs, or had it been announced publicly. There is so little chance for error in a photograph that such cases are always examined here. Confirmation is not always obtained. A striking instance of this kind is furnished by a photograph, X 7524, taken at Arequipa with the 13-inch Boyden telescope on May 22, 1896, at $14^h\ 20^m$ G. M. T. Miss A. J. Cannon found that this plate shows the spectra of *A. G. C.* 17312, 17407, and 17453, magns. 7.0, 7.2, and 7.5, respectively, but fails to show the spectrum of the brighter star *A. G. C.* 17270, mag. 6.0. Apparently this is an Algol star observed at one minimum only. On 153 other plates the star appears of its normal brightness. On a photograph, C 7354, taken at Cambridge with the 11-inch Draper telescope on December 18, 1894, at $11^h\ 8^m$ G. M. T., the star, $+42^\circ$ 4182, mag. 9.1 was found by Miss L. D. Wells to be

absent, although stars two and a half magnitudes fainter were shown. On plate C 7353, taken twelve minutes earlier, and on 259 other plates it appears of its normal brightness. An adjacent defect in the film of the first plate is perceptible, and perhaps explains the absence of this star. EDWARD C. PICKERING.

June 10, 1899.

NOTE ON METEOR PHOTOGRAPHY.

IN his note on meteor-photograms, taken simultaneously at Cambridge and Blue Hill (*Harvard College Observatory Circular* No. 40), Professor Pickering describes a method for determining by photography radiants and velocities of bright sporadic meteors.

At both stations the cameras were pointed to the zenith and clamped; from the plates obtained thus the declination of the radiant is found. In order to find Right Ascension, Professor Pickering proposes to install at both stations equatorially mounted cameras, driven by clockwork. To find the angular velocity he intends to photograph the spectra of the meteors on a plate oscillating like a pendulum.

I wish to point out that Declination, Right Ascension, angular velocity, and time of apparition can be found easily by four cameras, pointed to the zenith and fixed, three of them at one station, the fourth at another station. In the first of the three cameras the plate is fixed, in the second it revolves once in the time of exposure, say in four, six, or eight hours. The third plate rotates quickly, say once in eight seconds.

The mechanism of the cameras permits them to be pointed exactly to the zenith, and the image of the zenith-point coincides with the center of rotation, which is indicated beforehand on each plate by a circle traced near the periphery. The positions of the plates in cameras 1 and 2 at the beginning of exposure is marked by equal dashes on the periphery of this circle.

The meteor's trails on both plates have the same form and position. If we now superpose the two plates and bring both trails and centers into coincidence, we can find the angular displacement of the two dashes, from this the time of apparition, and from that time the position of the stars around the zenith at both stations. We can now transfer both trails onto a chart of stars and deduce the Declination and Right Ascension of the radiant.

The quickly rotating plate in the third camera serves to determine the angular velocity of the meteor at every point of its trace. By the rotation of the plate and of the meteor's trace a characteristic curve is formed, showing at first sight the direction of the meteor's trace. The origin of the trails will be continued in the same direction as the rotation of the plate.

By superposing this curve and the trail upon the fixed plate, different intersections in different positions of the plate will be obtained. The distance between the origin of the trail on the fixed plate and between the intersection is equal to the arc described by the meteor during the time deduced from the angular displacement of the origin of trail on the quickly rotating plate and on the first fixed plate.

My method is equally applicable with all four cameras directed to a point different from the zenith.

JOSEF JAN FRIČ.

PRAGUE,
April 15, 1899.

Reviews.

Die Photographie der Gestirne, von Dr. J. Scheiner, Professor der Astrophysik an der Universität Berlin und Astronom am K. Astrophysikalischen Observatorium zu Potsdam (pp. iv + 382, 1 plate and 52 figures, with an atlas of 11 plates. Leipzig: Engelmann, 1897).

Astronomical photography may be said to have begun with Daguerre himself, who upon Arago's suggestion took a photograph of the Moon in 1839. While this photograph showed none of the details of the Moon's surface yet it suggested the possibilities that lay in photography as an aid to astronomy. How great these possibilities were, the achievements of the last few years have amply testified; and no doubt this branch of astronomy is still in its infancy if we may judge by the rapid increase in the number and importance of the researches that are made with its aid.

Excepting the excellent little work by Konkoly (*Anleitung zur Himmelsphotographie*), which deals mainly with the manipulation of instrument and plates, no treatise on the subject has appeared until the present work by Professor Scheiner. This lack is no doubt due to the rapid strides which are being made in the subject and the large number of questions still unanswered. With the risk of being soon behind date, Professor Scheiner has wisely thought it time to put together in one convenient volume an account of whatever has been done on the subject. The work may be considered as making one of a uniform Potsdam series, the others being *Die Spectralanalyse der Gestirne*, 1890, by the same author, and *Die Photometrie der Gestirne*, 1897, by Professor Dr. G. Müller.

The author divides his subject into three parts:

I. The production of astronomical photographs and their utilization.

II. Photographic photometry and the nature of photographic images.

III. History of astronomical photography and the results it has yielded.

Part I opens with a discussion of the peculiarities of various emulsions, developers and processes of development, as a result of which the author is enabled to set down a number of valuable precepts, one or the other of which is to be followed according to the requirements of the case in hand. For example, if a photograph is taken with the intention of measuring it, the treatment will be different from that employed where mere detail is sought after in the object photographed. The author points out very clearly the requirements which distinguish an objective intended for photographic work from the ordinary refractor. Some points that are of little or no interest in the latter case become important for photography. Thus *diffraction rings* occasion little trouble in visual observations because of their faintness compared with the central image; but the sensitive film of the photographic plate has the power of accumulating whatever light energy falls upon it, and images may thus be obscured by even faint diffraction rings. For the same reason *spherical aberration* must be corrected with the greatest care, and *ghosts* due to reflection from the lens surfaces must be avoided. It should be observed, however, that these cause annoyance only in long exposures. Photographs intended for measurement are usually exposed for only a few minutes at the most, and in this case the requirements are hardly more exacting than for visual work.

The author distinguishes two kinds of distortions to which photographic images are liable: *geometric*, or those due to the fact that the plate is plane instead of spherical, and *optical*, due to peculiarities in the objective. The former are well understood and easily allowed for, but the latter can hardly be predicted, and in the most refined work ought to be investigated for each particular instrument. For any objective in which spherical aberration has been corrected the image of a star which lies on the optical axis will be small, well-defined and capable of exact measurement. The case is different with a star far from the axis, and unless especial care has been taken in the manufacture of the objective the image of such a star will present an unsymmetrical appearance, the densest part not occupying the center. The measures of such images are difficult and liable to systematic error. Still a third kind of distortion is sometimes spoken of, namely, that of the sensitive film after development. The author adduces some experimental evidence to show that such distortions are not greatly to be feared. The reviewer may be permitted to add that, by the inter-comparison of eight plates[1] each of which contained the images of

[1] *Annals of the N. Y. Academy of Sciences*, **10**, 273.

thirty-three particular stars in Praesepe, he found the probable error of a single coördinate to be

$$\pm 0.070''$$

which includes not only distortions of the film, but optical distortions, uncertainty in division errors and many other possible sources of error. Moreover, the plates were the old wet plates, taken in 1870 and 1877, but not measured until 1897; it is not too much to assume that distortions on such plates will be larger than on modern plates measured soon after exposure.

After an admirable chapter devoted to the description of particular photographic instruments, follows the longest and perhaps the most important chapter in the book, on the methods employed for the measurement and reduction of photographs. Here, as elsewhere, the author has adhered to the historical mode of treatment, and this, in the reviewer's opinion, lessens somewhat the value of the chapter. To an astronomer seeking information as to the best procedure to attain a particular end it would have been better to omit some of the earlier methods which, though undoubtedly of historical interest, have been superseded by later methods. It would have added much to the utility of the chapter to have had numerical examples, or better, the same example worked out by various methods. These methods have been reproduced by the author in the original notations and with essentially no change in the manner of presentation. The reason assigned for pursuing this course is that reference to the original memoirs is thus made easier, but the author has thereby neglected an opportunity for introducing a much needed uniformity of notation which would have been highly appreciated by the class of readers for whom the work is intended.

The author characterizes Turner's method as not being *rigorous*. It will be remembered that Turner applies no correction for refraction to the measured coördinates, and then shows that the "standard coördinates" of any star may be obtained by equations of the form:

$$X = ax + by + c$$
$$Y = dx + ey + f.$$

If corrections for refraction had been applied we should have had four instead of six coefficients in the second members, because of the relations

$$a - e = 0\,, \quad b + d = 0.$$

In other words, Turner obviates the necessity of computing the refrac-

tion and substitutes two least-square solutions of three unknowns each for a single one with four unknowns. But the solution in the latter case is by no means as formidable as is usual, because of the way in which some of the coefficients are repeated in the equations of condition.[1] Moreover, we may employ abridged refraction formulæ,[2] which are simply applied and entail the use of no more than four unknowns. Thus Turner's method is very little if at all shorter than the method here very briefly outlined, and has the disadvantage of introducing two additional unknowns which can be determined with far greater precision from the well-understood laws of differential refraction than from the positions of a few images upon a photographic plate.

Two of the best methods for the reduction of single plates, those of Jacoby and Henry, do not appear in the work because, in one case at least, they were published too late to admit of insertion. The *réseau* is not mentioned in this chapter, and only a few words are devoted to it in a previous one. While originally intended to eliminate possible distortions of the film, the *réseau* permits much simplification in the measuring machine, and insures greater accuracy and rapidity in the measures. On the other hand, it has been found very difficult to make them sufficiently permanent, and no small labor is involved in the investigation of their errors. But the advantages arising from their use are so great that, no doubt, the efforts of astronomers and instrument makers will be directed toward making them more durable, and perhaps also easier of investigation.

The last chapter of Part I deals with the application of photography to the automatic registration of star-transits, etc. In spite of the great advantage arising from the annihilation of personal equation, the practical utility of such instruments must still be regarded as in the experimental stage.

Part II is the most complete exposition of photographic photometry which has as yet appeared. Many of the results are due to the author's own labors, and some are here announced for the first time. The most important practical problem in this subject is to determine the magnitudes of stars from a given plate. It thus becomes necessary to investigate the nature of photographic images and inquire how their diameters vary with the duration of exposure and the intensity of the star's light. Early investigators assumed the erroneous law,

[1] *M. N. of R. A. S.*, May 1896, and *Annals of the N. Y. Academy of Sciences*, 10, 243.

[2] *Astronomical Journal*, No. 430.

intensity $\times$ time of exposure $=$ a constant, that is, they took it for granted that if the time of exposure was doubled for a certain star, the resulting image would be identical with that of a star twice as bright. It is now well known that this law is not even a good approximation. Indeed, for long exposures, while the image steadily broadens, the center, instead of becoming more intense, may actually become fainter. The case is not dissimilar to that of some chemical solutions which form precipitates on the addition of certain reagents, but are again dissolved when the latter are added to excess. As to the law which governs the broadening of the image, no really satisfactory exposition has yet been given. So many and such complex causes seem to enter that perhaps the best that can be done is to determine the relation experimentally. The author gives preference to the form

$$r = A + B \times \log t,$$

where r is the radius of the image, t the duration of exposure, and A and B are constants. Although derived originally from experiment, some considerations are adduced to show that this relation has a physical basis, at least to the extent of being a first approximation.

The author recommends the following process for deducing magnitudes from a plate: determine a and b in the formula

$$\text{magnitude} = a + b \times \text{diameter of image}$$

in such a way as to secure the best agreement between the photographic and visual magnitudes of as many stars upon the plate for which the latter are known. The formula may then be safely applied to unknown stars so long as there is a range of not more than four or six magnitudes. It is interesting to compare this simple formula with the one used by Kapteyn in his work for the Cape Durchmusterung, viz.,

$$\text{magnitude} = \frac{A}{B + \text{diameter}},$$

where A and B are determined as for Scheiner's formula.

Part III is an historical review of astronomical photography, and forms a most interesting addition to the theoretical discussions of the former part of the work. The somewhat novel but successful plan is followed of dividing the subject in subtitles, such as Sun, Moon, planets, etc., and of treating the history of each one of these independently of the others.

The work is concluded with an exhaustive bibliography of the entire subject. An index to the work is not wanting, nor do any pains seem to have been spared to make the book as useful and attractive as possible; it may be recommended as well-nigh indispensable to those interested in any branch of the subject. F. S.

UKIAH, CALIFORNIA,
July 8, 1899.